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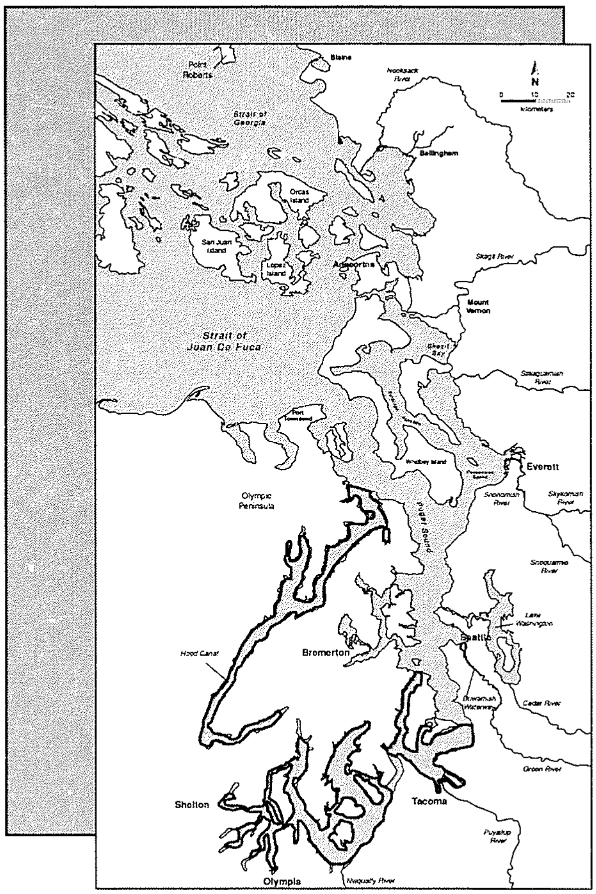
Sediment Quality in Puget Sound

Year 3 - Southern Puget Sound

July 2002



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General information and all data generated during this survey can be accessed from Ecology's Marine Sediment Monitoring website:
http://www.ecy.wa.gov/programs/eap/mar_sed/msm_intr.html

and the Sediment Quality Information System (SEDQUAL) website:
http://www.ecy.wa.gov/programs/tcp/smu/sedqualfirst.html

Notice

Sediment Quality in Puget Sound

Year 3 - Southern Puget Sound

July 2002

by

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Waterbody Numbers

WA-10-0010	WA-15-0110
WA-10-0030	WA-15-0120
WA-13-0010	WA-15-0130
WA-13-0020	WA-17-0010
WA-14-0010	WA-PS-0070
WA-14-0020	WA-PS-0090
WA-14-0050	WA-PS-0100
WA-14-0110	WA-PS-0250
WA-14-0130	WA-PS-0270
WA-15-0060	WA-PS-0290
WA-15-0080	WA-PS-0300

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Acronyms and Abbreviations

AVS/SEM –	acid volatile sulfides/ simultaneously-extracted metals
AED –	atomic emission detector
B[a]P –	benzo[a]pyrene
BNA –	base/neutral/acid organic chemical analysis
CAS –	Columbia Analytical Services
CLIS –	Central Long Island Sound
COH –	chlorinated organic hydrocarbons
CSL –	cleanup screening level
CV –	coefficient of variation
DCM –	dichloromethane
DMSO –	dimethylsulfoxide
EAP –	Environmental Assessment Program
EC50 –	50% effective concentration; concentrations of the extract that inhibited luminescence by 50% after a 5-minute exposure period (Microtox™ analysis)
EMAP –	Environmental Monitoring and Assessment Program
ERL –	effects range low (Long et al., 1995)
ERM –	effects range median (Long et al., 1995)
HCH–	Hexachlorocyclohexane
HRGS –	human reporter gene system
LC50 –	lethal concentration for 50% of test animals
LOEC –	lowest observable effects concentration
LPL –	lower prediction limit
MEL –	Manchester Environmental Laboratory
MESA –	Marine Ecosystems Analysis
MSD –	minimum significant difference
MSMT –	Marine Sediment Monitoring Team
NaCl –	sodium chloride
NOAA –	National Oceanic and Atmospheric Administration
NOEC –	no observable effects concentration
NS&T –	National Status and Trends Program
PAH –	polynuclear aromatic hydrocarbon
PCB –	polychlorinated biphenyl
PSAMP –	Puget Sound Ambient Monitoring Program
QL –	quantitation limit reported by Manchester Environmental Laboratory for chemistry data
RLU –	relative light unit
SDI –	Swartz's Dominance Index
SDS –	sodium dodecyl sulfate
SEDQUAL –	Sediment Quality Information System Database
SMS –	Sediment Management Standards
SQS –	sediment quality standard
TAN –	total ammonia nitrogen
TCDD –	tetrachlorodibenzo-p-dioxin
TEQ –	toxic equivalency quotients
TOC –	total organic carbon
UAN –	un-ionized ammonia
UPL –	upper prediction limit

Abstract

As a component of a three-year cooperative effort of the Washington State Department of Ecology and the National Oceanic and Atmospheric Administration, surficial sediment samples from 100 locations in southern Puget Sound were collected in 1999 to determine their relative quality based on measures of toxicity, chemical contamination, and benthic infaunal assemblage structure. The survey encompassed an area of approximately 858 km^2, ranging from East and Colvos Passages south to Oakland Bay, and including Hood Canal. Toxic responses were most severe in some of the industrialized waterways of Tacoma's Commencement Bay. Other industrialized harbors in which sediments induced toxic responses on smaller scales included the Port of Olympia, Oakland Bay at Shelton, Gig Harbor, Port Ludlow, and Port Gamble. Based on the methods selected for this survey, the spatial extent of toxicity for the southern Puget Sound survey area was 0% of the total survey area for amphipod survival, 5.7% for urchin fertilization, 0.2% for microbial bioluminescence, and 5-38% with the cytochrome P450 HRGS assay. Measurements of trace metals, PAHs, PCBs, chlorinated pesticides, other organic chemicals, and other characteristics of the sediments, indicated that 20 of the 100 samples collected had one or more chemical concentrations that exceeded applicable, effects-based sediment guidelines and/or Washington State standards. Chemical contamination was highest in eight samples collected in or near the industrialized waterways of Commencement Bay. Samples from the Thea Foss and Middle Waterways were primarily contaminated with a mixture of PAHs and trace metals, whereas those from Hylebos Waterway were contaminated with chlorinated organic hydrocarbons. The remaining 12 samples with elevated chemical concentrations primarily had high levels of other chemicals, including bis(2-ethylhexyl) phthalate, benzoic acid, benzyl alcohol, and phenol. The characteristics of benthic infaunal assemblages in south Puget Sound differed considerably among locations and habitat types throughout the study area. In general, many of the small embayments and inlets throughout the study area had infaunal assemblages with relatively low total abundance, taxa richness, evenness, and dominance values, although total abundance values were very high in some cases, typically due to high abundance of one organism such as the polychaete *Aphelochaeta* sp. N1. The majority of the samples collected from passages, outer embayments, and larger bodies of water tended to have infaunal assemblages with higher total abundance, taxa richness, evenness, and dominance values. Two samples collected in the Port of Olympia near a superfund cleanup site had no living organisms in them. A weight-of-evidence approach used to simultaneously examine all three "sediment quality triad" parameters, identified 11 stations (representing 4.4 km^2, 0.5% of the total study area) with sediment toxicity, chemical contamination, and altered benthos (i.e., degraded sediment quality), 36 stations (493.5 km^2, 57.5% total study area) with no toxicity or chemical contamination (i.e., high sediment quality), 35 stations (274.1 km^2, 32.0% total study area) with one impaired sediment triad parameter (i.e., intermediate/high sediment quality), and 18 stations (85.7km^2, 10.0% total study area) with two impaired sediment parameters (i.e., intermediate/degraded quality sediments). Generally, upon comparison, the number of stations with degraded sediments based upon the sediment quality triad of data was slightly greater in the central Puget Sound than in the northern and southern Puget Sound study areas, with the percent of the total study area degraded in each region decreasing from central to north to south (2.8, 1.3 and 0.5%, respectively). Overall, the sediments collected in Puget Sound during the combined 1997-1999 surveys were among the least contaminated relative to other marine bays and estuaries studied by NOAA using equivalent methods.

Executive Summary

Numerous studies of Puget Sound have documented the degree of chemical contamination and associated adverse biological effects within many different urbanized bays and harbors. Data from previous research have shown that contamination occurred in sediments, water, sea surface microlayers, fishes, benthic invertebrates, sea birds, and marine mammals in parts of Puget Sound. Severe toxicity of sediments in laboratory tests has been reported in previous studies along with significant alterations to resident benthic populations. Severe histopathological conditions in the organs of demersal fishes have been shown in many studies, sometimes accompanied by reduced reproductive success. Reproductive disorders were reported in resident marine mammals. Acute toxicity of sea surface microlayers has been shown in several studies in urban bays. Uptake and bioaccumulation of toxicants in sea birds and marine mammals has been observed. All these data, together, suggested that chemical contamination was toxicologically significant in Puget Sound. However, none of the previous surveys attempted to quantify the area or spatial extent of contamination or toxicant-related effects. Therefore, although numerous reports from previous studies indicated the severity or degree of contamination and adverse effects, none reported the spatial scales of the problems.

The overall goal of the cooperative program initiated by the Washington State Department of Ecology (Ecology) as a part of its Puget Sound Ambient Monitoring Program (PSAMP) and the National Oceanic and Atmospheric Administration (NOAA) as a part of its National Status and Trends Program (NS&TP) was to quantify the percentage of Puget Sound in which sediment quality was significantly degraded. The technical objectives of the cooperative assessment of bioeffects in Puget Sound were to:

1. Determine the incidence and severity of sediment contamination and toxicity;

2. Identify spatial patterns and gradients in sediment toxicity and chemical concentrations;

3. Estimate the spatial extent of toxicity and chemical contamination in surficial sediments as percentages of the total survey area;

4. Describe the composition, abundance and diversity of benthic infaunal assemblages at each sampling location;

5. Estimate the apparent relationships between measures of sediment toxicity, toxicant concentrations, and benthic infaunal assemblage indices; and

6. Compare the quality of sediment from northern, central, and southern Puget Sound measured in the three phases of this study.

The approach selected to accomplish this goal was to measure the components of the sediment quality triad at sampling locations chosen with a stratified-random design. One hundred samples were collected in southern Puget Sound during June/July, 1999, at locations selected randomly within 33 geographic strata. The study area extended from the vicinity of Des Moines to Shelton, plus all of Hood Canal. Strata were selected to represent conditions near major urban centers (e.g., Tacoma, Olympia) and less developed areas. The 33 strata were determined to encompass a total area of 858 km^2.

A battery of four toxicity tests was performed on all samples to provide information from a variety of toxicological endpoints. Results were obtained with an acute test of survival of marine amphipods exposed to solid phase sediments. The toxicity of sediment pore waters was determined with a test of fertilization success among sea urchin gametes. A microbial bioluminescence test of metabolic activity was performed in exposures to organic solvent extracts along with a cytochrome P450 HRGS activity test in exposures to portions of the same solvent extracts. Chemical analyses were performed on all samples to quantify the concentrations of trace metals, PAHs, PCBs, chlorinated pesticides, other organic chemicals, and the physical/sedimentological characteristics of the sediments. Chemical concentrations were compared to applicable numerical guidelines from NOAA and state standards for Washington to determine which samples were contaminated. Resident benthic infauna were collected to determine the relative abundance, taxa richness, taxa composition, and other characteristics of the invertebrate assemblages present in the sediments at each site.

The area in which highly significant toxicity occurred totaled 0% of the total area in the amphipod survival tests; 5.7% of the area in urchin fertilization tests of 100% pore waters; 0.2% of the area in microbial bioluminescence tests; and 5-38% of the area in the cytochrome P450 HRGS assays. The estimates of the spatial extent of toxicity measured in these tests of southern Puget Sound sediments generally were lower than the "national average" estimates compiled from many other surveys previously conducted by NOAA. Generally, they were comparable to the estimates for northern Puget Sound, but somewhat higher than what was observed in the central region. The large majority of the area surveyed was classified as non-toxic in these tests.

The laboratory tests indicated overlapping, but, different, spatial patterns in toxicity. Based upon analysis of all the data combined, several spatial patterns were apparent in this survey. Most obvious were the toxic responses in the two tests of organic solvent extracts observed in some of the industrialized waterways of Commencement Bay at Tacoma. The responses in samples from Thea Foss Waterway were very high in both the HRGS and Microtox™ tests. Significant responses were also observed in both the amphipod and urchin tests in one of the samples. The degree of toxicity in Hylebos and Middle waterways was lower, but, nonetheless, represented conditions considerably different from those observed elsewhere in the survey area. The toxicity observed in the waterways gradually diminished into the outer reaches of the bay and decreased again into East Passage.

Other industrialized harbors of southern Puget Sound in which sediments induced toxic responses included Port of Olympia, Oakland Bay at Shelton, Gig Harbor, and Port Ludlow. Sediments in most of the South Sound inlets and passages were relatively non-toxic in any of the tests. However, based upon the HRGS and Microtox™ tests of organic solvents, conditions in the southern Puget Sound inlets and channels were different (i.e., more toxic) than in the majority of Hood Canal.

Twenty of the 100 samples collected had one or more chemical concentrations that exceeded applicable, effects based sediment guidelines and/or Washington State standards. Among these samples, chemical contamination was highest in eight samples collected in or near the industrialized waterways of Commencement Bay. Samples from the Thea Foss and Middle Waterways were primarily contaminated with a mixture of PAHs and trace metals, whereas those from Hylebos Waterway were contaminated with chlorinated organic hydrocarbons. The remaining 12 samples with elevated chemical concentrations primarily had high levels of other chemicals, including bis(2-ethylhexyl) phthalate, benzoic acid, benzyl alcohol, and phenol. There was a distinct spatial pattern in contamination in Commencement Bay: i.e., high concentrations in the waterways diminished rapidly into the outer reaches of the bay. However, there were no other equally clear gradients elsewhere in the study area.

For all trace metals (excluding nickel), there were a total of 4 effects range-median (ERM), 3 sediment quality standard (SQS), and 3 cleanup screening level (CSL) samples exceeded respectively, encompassing a total of 0.84, 0.68, and 0.68%, respectively, of the total study area. Significant metals contamination occurred in Port Gamble Bay, Totten Inlet, and in both the Thea Foss and Middle Waterways of Commencement Bay, and mercury was the most commonly found contaminant. There were totals of 6, 4, and 1 samples with PAHs exceeding ERM, SQS, and CSL values, respectively, encompassing a total of 0.30, 0.23, and <0.01% of the study area. Contaminants were again observed in Port Gamble Bay and Commencement Bay, including both the Thea Foss and Middle Waterways. PCB chemicals exceeded guidelines and criteria in 2 (ERM) and 3 (SQS) stations in the Thea Foss and Hylebos Waterways, representing 0.04 and 0.07% of the study area. Other organic chemicals, including benzoic acid and benzyl alcohol exceeded SQS and CSL values in 5 or fewer samples, roughly representing 3% or less of the study area, including stations in Budd Inlet, Port of Olympia, Henderson Inlet, E. Anderson Island, and Hale and Pickering Passages. Hexachlorobenzene values exceeded the SQS value at all three stations in the Hylebos Waterway (representing 0.08% of the study area).

Although the study was not intended to determine the causes of toxicity in the tests, a number of statistical analyses were conducted to estimate which chemicals, if any, may have contributed to toxicity. As expected, strong statistical associations between measures of toxicity and complex mixtures of PAHs, pesticides, phenols, other organic chemicals, and several trace metals were observed. The strongest associations were those between cytochrome P450 HRGS induction and the concentrations of PAHs in the sediments. These relationships were observed previously in both northern and central Puget Sound.

As with the previous infaunal assemblage studies conducted in north and central Puget Sound (Long, et al. 1999a, 2000), benthic infaunal assemblages in south Puget Sound had a wide variety of characteristics in different locations and habitat types throughout the study area. Infaunal assemblages examined typically displayed relatively high abundance, taxa richness, evenness, and dominance values. Polychaetes were typically the most abundant taxa group (up to 93% of the infaunal composition), followed by arthropods (up to 75%), mollusks (up to 70%), echinoderms (up to 55%), and miscellaneous taxa (up to 33%). Two samples collected in the Port of Olympia near a superfund cleanup site had no living organisms in them. In general, many of the small embayments and inlets throughout the study area had infaunal assemblages with relatively low total abundance, taxa richness, evenness, and dominance values. In some of the small urban/industrial embayments however, cases were found where total abundance values were very high, typically due to high abundance of one organism such as the polychaete

Aphelochaeta sp. N1; the clam *Axinopsida serricata*; the amphipod *Aoroides spinosus*; or the brittlestar *Amphiodia urtica/periercta* complex. The majority of the samples collected from passages, outer embayments, and larger bodies of water tended to have infaunal assemblages with high total abundance, taxa richness, evenness, and dominance values.

Statistical analyses of the toxicity data and benthic data revealed few consistent patterns. The relationships between measures of benthic structure and chemical concentrations showed mixed results. Both taxa richness and the dominance index were negatively correlated with the concentrations of trace metals in the samples. Highly significant positive correlations indicated that the abundance of the benthos and the numbers of species increased as the concentrations of PAHs increased. In addition, the abundance of annelids and molluscs showed increasing abundance with increasing PAH concentrations. Therefore, these data suggest that the benthic assemblages were tolerant of the chemical concentrations in these samples and attracted to the sampled areas by other ecological factors.

A weight-of-evidence approach was used to simultaneously examine all three "sediment triad" parameters measured, defining each station based on the number of impaired parameters measured at the station. Four categories of sediment quality were generated, including "High Quality" (none of the sediment triad parameters impaired), "Intermediate/High Quality" (one sediment triad parameter impaired), "Intermediate/Degraded Quality" (two sediment triad parameters impaired), and "Degraded Quality" (all of the sediment triad parameters impaired).

There were 11 stations (representing 4.4 km^2, 0.5% of the total study area) with sediment toxicity, chemical contamination, and altered benthos (i.e., "degraded sediment quality"). Typically, these stations were shallow, represented a small area, were primarily located in major urban areas, and had relatively fine grain size and high TOC values. Infaunal assemblages typically had higher total abundance (usually due to one or two abundant dominant organisms), moderate taxa richness and evenness, lower dominance values, and were dominated by annelids (sometimes in high abundance), followed by molluscs, arthropods, echinoderms, and miscellaneous taxa. The polychaete species *Aphelochaeta* sp. N1 was the dominant taxon at ten of the eleven stations.

In contrast, 36 stations (representing 493.5 km^2, 57.5% of the total study area) displayed no toxicity or chemical contamination, and abundant and diverse infaunal assemblages. These stations typically included the larger, deeper inlets, basins, and passages of the more rural areas of south Puget Sound and Hood Canal, as well as a few smaller embayments. They tended to have coarser sediment with lower TOC content than those stations with degraded sediment quality. Infaunal assemblages at these stations had lower total abundance, and higher evenness and dominance values than those stations with degraded sediment quality.

Thirty-five stations (274.1 km^2, 32.0% total study area) had one impaired sediment triad parameter (i.e., intermediate/high quality sediments), and included stations with characteristics similar to those with high quality sediments. The remaining 18 stations (85.7km^2, 10.0% total study area) displayed two impaired sediment parameters (i.e., intermediate/degraded quality sediments), and included stations with characteristics similar to those with degraded sediments.

Generally, upon comparison, the number of stations with degraded sediments based upon the sediment quality triad of data was slightly greater in the central Puget Sound than in the northern and southern Puget Sound study areas, with the percent of the total study area degraded in each region decreasing from central to north to south (2.8, 1.3 and 0.5%, respectively). In comparison, the Puget Sound sediments were considerably less degraded than those from other NOAA sediment surveys conducted nationwide.

Data from these surveys of Puget Sound sediment quality can provide the basis for quantifying changes in sediment quality, if any, in future years. A probabilistic random, stratified sampling design and similar analytical methods could be used in the future to generate comparable data, allowing the measurement of change in Puget Sound sediment quality that can be expressed in terms of the percentage of area that is degraded.

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Introduction

Project Background

In 1996 the Washington Department of Ecology (Ecology) and the National Oceanic and Atmospheric Administration (NOAA) entered into a three year Cooperative Agreement to quantify the magnitude and extent of toxicity and chemical contamination of sediments in Puget Sound. This agreement combined the sediment monitoring and assessment programs of the two agencies into one large survey of Puget Sound.

Ecology's Marine Sediment Monitoring Team has conducted the Sediment Monitoring Component of the Puget Sound Ambient Monitoring Program (PSAMP) since 1989. This program used the sediment quality triad approach of Long and Chapman (1985) to determine relative sediment quality in Puget Sound. Preceding the joint surveys with NOAA, Ecology established baseline data for toxicity and chemical contamination of Puget Sound sediments (Llansó et al., 1998a) and characterized infaunal invertebrate assemblages (Llansó et al., 1998b) at 76 selected monitoring stations throughout Puget Sound. A portion of this baseline work is continuing at a subset of ten stations at the present time.

The National Status and Trends (NS&T) Program of NOAA has conducted bioeffects assessment studies in more than 30 estuaries and marine embayments nationwide since 1990 (Long et al., 2000). Most of these studies followed a random-stratified sampling design and the triad approach to estimate the spatial extent, magnitude, and spatial patterns in relative sediment quality and to determine the relationships among measures of chemical contamination, toxicity, and benthic infaunal structure within the study areas. Puget Sound was selected for such a study for a number of reasons. First, historical data showed the presence of toxicants in sufficiently high concentrations to cause adverse biological effects. Second, there was a lack of quantitative data on the spatial extent of toxicity in the area. Third, there was a possibility of a collaboration effort between NOAA and a state agency partner (Ecology) in performing the study.

The current joint project of Ecology and NOAA utilizes NOAA's random-stratified sampling design and the sediment quality triad approach for the collection and analyses of sediment and infauna. The project was broken into three sampling periods. Sediments were sampled in northern Puget Sound in 1997 (Long et al., 1999), central Puget Sound in 1998 (Long et al., 2000), and southern Puget Sound in 1999 (this report).

Site Description

The overall study area encompassed the basins and channels from the U.S./Canada border to the southern-most bays and inlets near Olympia and Shelton and included portions of Admiralty Inlet and Hood Canal (Figure 1). This region located in northwestern Washington is composed of a variety of interconnected shallow estuaries and bays, deep fjords, broad channels and river mouths. It is bounded by three major mountain ranges; the Olympics to the west, the mountains of Vancouver Island to the north, and the Cascade Range to the east. The northern end of Puget Sound is open to the Strait of Juan de Fuca and the Strait of Georgia, connecting it to the Pacific Ocean. The estuary extends for about 130 km from Admiralty Inlet at the northern end of the main basin to Olympia at the southern end and ranges in width from 10 to 40 km (Kennish, 1998).

The main basin of Puget Sound was glacially scoured with depths up to 300 m, has an area of 2600 km^2 and a volume of 169 km^3 (Kennish, 1998). Circulation in Puget Sound is driven by complex forces of freshwater inputs, tides, and winds. Puget Sound is characterized as a two-layered estuarine system with marine waters entering the Sound at the sill in Admiralty Inlet from the Strait of Juan de Fuca at depths of 100 to 200 m and freshwater entering from a number of large streams and rivers. Major rivers entering Puget Sound include the Skagit, Snohomish, Cedar, Duwamish, Puyallup, Stillaguamish, and Nisqually (Figure 1). The Skagit, Stillaguamish, and Snohomish rivers account for more than 75% of the freshwater input into the Sound (Kennish, 1998). The mean residence time for water in the central basin is approximately 120-140 days, but is much longer in the isolated inlets and restricted deep basins in southern Puget Sound.

The bottom sediments of Puget Sound are composed primarily of compact, glacially-formed, clay layers and relict glacial tills (Crandell et al., 1965). Major sources of recent sediments are derived from shoreline erosion and riverine discharges.

Puget Sound is a highly complex, biologically important ecosystem that supports major populations of benthic invertebrates, estuarine plants and kelp, resident and migratory fish, marine birds, and marine mammals. All of these resources depend upon uncontaminated habitats to sustain their population levels. The Sound is bordered by both undeveloped lands and highly urbanized and industrialized areas. Major urban centers include the cities of Seattle, Tacoma, Olympia, Everett, Bremerton, and Bellingham.

The portion of the Puget Sound study conducted in 1999 focused upon the southern region of the study area, i.e., from the southern boundary of the 1998 study area (i.e., Maury Island/Des Moines) to the southern end of Puget Sound, including Hood Canal (Figure 1). The 1999 study area, therefore, included portions of the main basin of Puget Sound, Commencement Bay, Case Inlet, Carr Inlet, Budd Inlet, Henderson Inlet, Eld Inlet, Oakland Harbor, and Pickering Passage.

Toxicant-Related Research in Puget Sound

Puget Sound waters support an extremely diverse spectrum of economically important biological resources. In addition to extensive stocks of salmon, a variety of other species (e.g. cod, rockfish, clams, oysters and crabs) support major commercial and recreational fisheries. Studies have shown that high concentrations of toxic chemicals in sediments are adversely affecting the biota of the sound via detritus-based food webs. Studies of histopathological, toxicological, and ecological impacts of contaminants have focused primarily on biota collected in areas potentially influenced by port activities and municipal or industrial discharges (Ginn and Barrick, 1992). Therefore, the majority of studies of toxicant effects have focused on Elliott and Commencement bays.

Within the 1999 survey area, most of the previous research was done in Commencement Bay. Research was conducted on the presence, concentrations, and biological significance of toxicants. Much of this research was conducted to quantify chemical concentrations in sediments, animal tissues, water, marine mammals, marine birds, and sea surface microlayers. Some studies also were conducted to determine the history of chemical contamination using analyses of age-dated sediment cores. The objectives of these studies often included analyses of the biological significance of the chemical mixtures. Biological studies have been conducted to determine the frequency of lesions and other disorders in demersal fishes; the toxicity of sediments; the toxicity of water and sea surface microlayers; reproductive dysfunction in fishes, birds, and mammals; and the degree of effects upon resident benthic populations.

Studies performed by NOAA through the MESA (Marine Ecosystems Analysis) Puget Sound Project determined the concentrations of toxic substances and toxicity in sediments with a battery of acute and chronic tests performed on samples collected throughout most of the Puget Sound region. However, early in the MESA Project, attention was focused upon the recurring problem of acute mortality among bivalve embryos in samples of water from South Puget Sound (Cardwell et al., 1979). Experimental research demonstrated that toxicity was worst in several of the inlets of the region and probably caused by a combination of factors that included high concentrations of toxic dinoflagellates and ammonia.

The MESA sediment toxicity surveys were conducted in a sequence of four phases in the early 1980's. In the first phase (Chapman et al., 1982), samples collected from 97 locations were tested with several bioassays. Samples were collected mainly at selected locations within Elliott Bay, Commencement Bay, and Sinclair Inlet. Tests were performed to determine survival of oligochaetes, amphipods, and fish; respiration measurements of oligochaetes; and chromosomal damage in cultured fish cells. The results of multiple tests indicated that some portions of Elliott Bay near the Denny Way CSO and several of the industrialized waterways of Commencement Bay were highly toxic and samples from Port Madison and Birch Bay were among the least toxic.

In the second phase of the MESA Puget Sound sediment toxicity surveys, tests were performed to identify diminished reproductive success among test animals exposed to sediments (Chapman et al., 1983). These tests involved oyster embryo development, surf smelt development, and a polychaete worm life cycle bioassay. Samples from the lower Duwamish River and the Commencement Bay waterways were the most toxic. In the third phase, 22 samples were collected in Everett Harbor, Bellingham Bay, and Samish Bay in northern Puget Sound and tested with the same battery of tests used in the first phase of the studies (Chapman et al., 1984a). Toxicity was less severe in these 22 samples than in comparable samples from Elliott and Commencement bays. However, the sediments from Everett Harbor demonstrated greater toxicity than those from Bellingham Bay and samples from Samish Bay were the least toxic.

In the fourth and final phase, sediment quality was determined with the introduction of the sediment quality triad approach (Chapman et al., 1984b; Long and Chapman, 1985). Matching chemical, toxicity, and benthic data were compiled to provide a weight of evidence to rank sampling sites. Data from several locations in Elliott and Commencement bays and Sinclair Inlet were compared with data from Case Inlet and Samish Bay. As observed in the previous phases, the data clearly showed a pattern of low sediment quality in samples from the urbanized areas relative to those from the more rural areas.

Histopathology studies that included southern Puget Sound indicated that biological impacts such as hepatic neoplasms, intracellular storage disorders, and lesions in fish were pollution-related. They were found most frequently near industrial urban areas, including portions of Elliott Bay, Sinclair Inlet, Eagle Harbor and the nearshore waterways of Commencement Bay (Malins et. al., 1980, 1982, 1984; U.S. EPA, Region X, 1986). Fish with such disorders often had the highest concentrations of organic chemicals and trace metals in their tissues.

Studies in which toxicity tests were performed confirmed histopathological findings that pollution-induced biotic impacts were more likely to occur near industrial urban areas (Chapman et. al., 1982; Malins, et. al., 1982; Malins et. al. 1988; Llansó et. al., 1998). Numerous analyses of contaminant exposures and adverse effects in resident demersal fishes were conducted in most of the urbanized bays and harbors (Malins et. al. 1980, 1982, 1984). Data from these studies demonstrated that toxicant-induced, adverse effects were apparent in fish collected in urban harbors of Puget Sound and the prevalence of these effects was highest in areas with highest chemical concentrations in the sediments to which these fish were exposed. The incidence of neoplastic lesions was highest among fish from Eagle Harbor. Similar kinds of analyses were performed on resident marine birds and marine mammals, demonstrating that chemical levels in these animals were elevated in regions of Elliott and Commencement bays relative to animals from the Strait of Juan de Fuca and elsewhere (Calambokidis et. al., 1984).

A summary of available data from sediment toxicity tests performed in Puget Sound through 1984 (Long, 1984) indicated that sediments were most toxic in samples from the waterways of Commencement Bay, Elliott Bay off the Denny Way CSO, inner Sinclair Inlet, lower Duwamish Waterway, Quilcene Bay, Bellingham Bay, and inner Everett Harbor. Significant results were reported in acute survival tests with amphipods, sublethal assays of respiration rate changes, tests of mutagenic effects in fish cells, and oyster embryo development tests. Swartz et al. (1982) demonstrated the remarkable differences in sediment toxicity in the Commencement Bay waterways versus that of the open bay. Poor amphipod survival in their survey was coincidental with low amphipod abundance in the benthic samples and elevated chemical concentrations.

Studies of invertebrate communities conducted in central Puget Sound have indicated significant losses of benthic resources in some areas with high chemical concentrations (Malins, et. al., 1982; Kisker, 1986; Chapman et. al., 1984; Becker et. al., 1987, Llansó et. al., 1998). The longest term and most extensive sampling of infaunal invertebrate communities were conducted by the Puget Sound Ambient Monitoring Program, established in 1989. The program sampled 20 sites in southern Puget Sound, 15 of which were sampled yearly from 1989-95 and 5 that were sampled once in 1991 and once again in 1994.

The colonization rates and species diversity of epifaunal communities that attached to vertical test surfaces was lowest at locations in the lower Duwamish River as compared to sites elsewhere in Puget Sound (Schoener, 1983). In the same study, colonization rates were intermediate at locations in Milwaukee, Blair, and Hylebos waterways near Commencement Bay. The highest rates were observed in locations monitored at Manchester and outer Elliott Bay.

Samples of sea surface microlayers from Elliott Bay were determined to be contaminated and toxic in acute tests done with planktonic life stages of marine fish (Hardy and Word, 1986;

Hardy et al., 1987a, 1987b). Historical trends in chemical contamination were reviewed and the physical processes that influence the fate and transport of toxicants in regions of Puget Sound were summarized in a variety of reports (Dexter et. al., 1981; Barrick, 1982; Konasewich et al., 1982; Long 1982; Crecelius et al., 1985).

Following the work by NOAA, additional studies of chemical contamination were supported by the Puget Sound National Estuary Program (PSEP). The PSEP studies further identified spatial patterns in sediment contamination, toxicity, and benthic effects in selected urban embayments and reference areas throughout Puget Sound. In an exhaustive assessment of sediment quality in the nearshore waterways of Commencement Bay, data were collected on contamination and toxicity of sediments, the abundance and diversity of infaunal macroinvertebrates, and the prevalence of histopathological disorders in demersal fishes (Tetra Tech, 1985). This study further verified the findings of the NOAA studies, namely, that the industrialized waterways were highly contaminated relative to the more rural Carr Inlet of South Puget Sound. It also demonstrated the significant differences in chemical mixtures that occurred among the different waterways as a function of the types of nearby sources.

In 1988, the PSEP funded a study of four embayments (Dyes Inlet, Gig Harbor, Port Angeles Harbor, and Oak Harbor/Shelton) to determine the degree of contamination and biological effects in sediments and fish (Crecelius et al., 1989). The data indicated that chemical concentrations were lower in these four bays than in Elliott and Commencement bays. Also, none of the sediment samples was toxic in amphipod bioassays.

The PSEP also formulated tentative plans for cleaning up some of the more contaminated sites. Although extensive deep portions of Puget Sound and most rural bays are relatively contaminant-free, parts of the bays bordering urban, industrialized centers contained high concentrations of toxic chemicals (Long and Chapman, 1985; Llansó et. al., 1998a). Other programs and studies, including the Puget Sound Dredged Disposal Analysis Program (PTI, 1989) and the Puget Sound Ambient Monitoring Program (Llansó et al., 1998a,b), characterized baseline sediment quality conditions and trends throughout Puget Sound.

In addition to these large-scale studies, federal, state and local government, as well as private industry, has conducted a vast number of smaller, localized studies on Puget Sound sediments, primarily for regulatory purposes. These studies have focused on the level of chemical concentrations in sediments, the incidence of abnormalities and diseases in fish and benthic invertebrates, the level and degree of sediment toxicity to various bioassay organisms, the relationship between sediment contamination and the composition of benthic invertebrate communities, and to a lesser extent, the associations between sediment contamination, toxicity, and resident marine bird and mammal populations.

Information gathered from the surveys of toxicity in sediment, water, and microlayer and the studies of adverse effects in resident benthos, fish, birds and mammals confirmed that conditions were most degraded in urbanized embayments of Puget Sound, including Elliott and Commencement bays (Long, 1987). All of the data from the historical research, collectively, served to identify those regions of Puget Sound in which the problems of chemical contamination were the worst and in which management actions of some kind were most needed (NOAA, 1987). However, although these previous studies provided information on the degree and spatial patterns in chemical contamination and effects, none attempted to quantify the spatial extent of either contamination or measures of adverse effects. None of the previous studies generated reliable estimates of the spatial scales of chemical contamination or adverse effects.

The Sediment Quality Information System (SEDQUAL) Database

Ecology's Sediment Management Unit has compiled a database that includes sediment data from over 430 Puget Sound sediment surveys of varying size and scope. The Sediment Quality Information System (SEDQUAL) database includes approximately 688,000 chemical, 140,000 benthic infauna, and 35,000 bioassay analysis records from over 12,000 sample collection stations throughout Puget Sound. For the southern Puget Sound study area defined in this report, the SEDQUAL database currently contains sediment data from 3141 samples (218 surveys, Appendix A) collected from 1950-2000. Using the analytical tools available in SEDQUAL, these data can be compared to chemical contaminant guidelines from NOAA and criteria set forth in the Washington State Sediment Management Standards (SMS), Chapter 173-204 WAC., the Sediment Quality Standards (SQS) and Puget Sound Marine Sediment Cleanup Screening Levels (CSL). Of the 3141 SEDQUAL samples from southern Puget Sound, 772 have chemical contaminant levels that exceeded at least one SQS or CSL value. The majority of these stations are located near population centers, urban and industrial areas, and ports, including Commencement Bay, Hylebos Waterway, Blair Waterway, Middle Waterway, Thea Foss Waterway, and Port of Olympia (Figure 2). A summary of the chemicals found in these southern Puget Sound SEDQUAL samples which exceeded SMS values, including their sample location and total number of samples, is given in Appendix B. In southern Puget Sound, all 47 chemicals with SMS values were exceeded on at least one occasion.

Goals and Objectives

The shared goal of this study for both the PSAMP Sediment Monitoring Component and NOAA's nationwide bioeffects assessment program was to characterize the ecotoxicological condition of sediments, as well as benthic infaunal assemblage structure, as a measure of adverse biological effects of toxic chemicals in southern Puget Sound. Based upon chemical analyses of sediments reported in previous studies, it appeared that there were relatively high probabilities that concentrations were sufficiently high in some regions of the study area to cause acute toxicity and infaunal assemblage alterations. Data from toxicity tests were intended to provide a means of determining whether toxic conditions, associated with high concentrations of chemical pollutants, actually occurred throughout any of the area. Examination of infaunal assemblages was intended to determine whether sediment chemistry and toxicity conditions are correlated with patterns in infaunal community structure. Underlying these goals was the intent to use a stratified-random sampling design that would allow the quantification of the spatial extent of degraded sediment quality.

Based on the nature of sediment contamination issues in Puget Sound, and the respective mandates of NOAA and the state of Washington to address sediment contamination and associated effects in coastal waters, the objectives of the cooperative assessment of bioeffects in Puget Sound were to:

1. Determine the incidence and severity of sediment toxicity in selected laboratory tests;

2. Identify spatial patterns and gradients in sediment toxicity and chemical concentrations;
3. Estimate the spatial extent of toxicity and chemical contamination in surficial sediments as percentages of the total survey area;
4. Describe the composition, abundance and diversity of benthic infaunal assemblages at each sampling location;
5. Estimate the apparent relationships between measures of sediment toxicity, toxicant concentrations, and benthic infaunal assemblage indices; and
6. Compare the quality of sediment from northern, central, and southern Puget Sound measured in the three phases of this study.

This report includes a summary of the data collected in 1999 and correlation analyses to examine toxicity, chemistry, and infaunal relationships. Results of further analyses relating toxicity, chemistry, and infaunal structure throughout the entire survey area will be reported in a subsequent document.

Methods

Standardized methods described in the Puget Sound Estuary Program protocols (PSEP, 1996a), previously used in the 1997 and 1998 surveys of northern and central Puget Sound (Long et al., 1999a, 2000), and previously followed in surveys of sediment quality conducted elsewhere in the U.S. by NOAA (Long et al., 1996) were followed in this survey. Any deviations from these protocols are described below.

Sampling Design

By mutual agreement between Ecology and NOAA, the study area was established as the area extending from the southern boundary of the 1998 study area (i.e., Maury Island/Des Moines) to the southern end of Puget Sound, including Hood Canal. The 1999 study area, therefore, included portions of the main basin of Puget Sound, Colvos Passage, Commencement Bay, Case Inlet, Carr Inlet, Budd Inlet, Henderson Inlet, Eld Inlet, Oakland Harbor, and Pickering Pass (Figure 3a-3e). All samples were collected in depths of 6 ft. or more (mean lower low water), the operating limit of the sampling vessel.

A stratified-random sampling design similar to those used in previous surveys conducted nationwide by NOAA (Long et al., 1996) and in the first two years of this study in northern and central Puget Sound (Long et al., 1999; 2000), was applied in southern Puget Sound. This basic approach, first developed by US EPA as part of the Environmental Monitoring Assessment Program (Paul, et al., 1992; Schimmel et al., 1994), combines the strengths of a stratified design with the random-probabilistic selection of sampling locations within the boundaries of each stratum. Data generated from multiple samples collected within each stratum can be attributed to the area (i.e., spatial area as acres, km^2 or percent of area) of the stratum. Therefore, these data allow us to estimate the spatial extent of degraded conditions with a quantifiable degree of confidence (Heimbuch, et al., 1995; Paul, et al., 1992). Strata boundaries were established to coincide with the dimensions of major basins, bays, inlets, waterways, etc. in which hydrographic, bathymetric and sedimentological conditions were expected to be relatively homogeneous (Figure 3a). Data from Ecology's SEDQUAL database were reviewed to assist in establishing strata boundaries.

The study area was subdivided into 33 irregular-shaped strata (Figure 3a-e). Large strata were established in the open waters of the area where toxicant concentrations were expected to be uniformly low (e.g., Case Inlet, Carr Inlet, Central Puget Sound basin, Colvos Passage, and Hood Canal). This approach provided the least intense sampling effort in areas known or suspected to be relatively homogeneous in sediment type and water depth, and relatively distant from contaminant sources. In contrast, relatively small strata were established in urban and industrial harbors nearer suspected sources in which conditions were expected to be heterogeneous or transitional (e.g., Commencement Bay, Port of Olympia, and Port of Shelton). As a result, sampling effort was spatially more intense in the small strata than in the large strata. The large strata were roughly equivalent in size to each other as were the small strata to one another (Table 1). Areas with known topographic features that could not be sampled with our methods (i.e., vanVeen grab sampler) were excluded from the strata design (e.g., Dana Passage, which was known to have rocky substrate).

Within the boundaries of each stratum, all possible latitude/longitude intersections had equal probabilities of being selected as a sampling location. The locations of individual sampling stations within each stratum were chosen randomly using GINPRO software developed by NOAA applied to digitized navigation charts. In most cases three samples were collected within each stratum; however, four stations were sampled in several strata expected to be heterogeneous in sediment quality. Four alternate locations were provided for each station in a numbered sequence. The coordinates for each alternate were provided in tables and were plotted on the appropriate navigation chart. In a few cases, the coordinates provided were inaccessible or only rocks and cobble were present at the location. In these cases, the first set of station coordinates was rejected and the vessel was moved to the next alternate. In the majority of the 100 stations, the first alternate location was sampled. Final station coordinates are summarized in the navigation report (Appendix C).

Sample Collection

Sediments from 100 stations were collected during June 1999 with the 42' research vessel *Kittiwake*. Each station was sampled only once. Differential Global Positioning System (DGPS) with an accuracy of better than 5 meters was used to position the vessel at the station coordinates. The grab sampler was deployed and retrieved with a hydraulic winch.

Prior to sampling each station, all equipment used for toxicity testing and chemical analyses was washed with seawater, Alconox soap, acetone, and rinsed with seawater. Sediment samples were collected with a double 0.1 m^2, stainless steel, modified vanVeen grab sampler. Sediment for toxicity testing and chemical analyses was collected simultaneously with sediment collected for the benthic community analyses to ensure synoptic data. Upon retrieval of the sampler, the contents were visually inspected to determine if the sample was acceptable (jaws closed, no washout, clear overlying water, sufficient depth of penetration). If the sample was unacceptable, it was dumped overboard at a location away from the station. If the sample was acceptable, information was recorded on station coordinates and the sediment color, odor, and type in field logs.

One 0.1 m^2 grab sample from one side of the sampler was collected for the benthic infaunal analyses. Procedures described for collecting benthos in Puget Sound (PSEP, 1987) and in NOAA's sediment assessments (Gotthom and Harmon, 2000) include collection of multiple samples at each location to lower costs, thereby precluding statistical comparisons of benthic community indices among stations. All infaunal samples were rinsed gently through nested 1.0 and 0.5 mm screens and the organisms retained on each screen were kept separate. Organisms were preserved in the field with a 10% aqueous solution of borax-buffered formalin.

From the other side of the sampler, sediment was removed for chemical and toxicity tests using a disposable, 2 mm deep, high-density polyethylene (HDPE) scoop. The top two to three cm of sediment was removed with the scoop and accumulated in a HDPE bucket. The sampler was deployed and retrieved from three to six times at each station, until a sufficient amount (about 7 l) of sediment was collected in the bucket. Between deployments of the grab, a Teflon plate was placed upon the surface of the sample, and the bucket was covered with a plastic lid and to avoid contamination, oxidation, and photo-activation. After 7 l of sediment were collected, the sample was stirred with a stainless steel spoon to homogenize the sediments and then transferred to individual jars for the various toxicity tests and chemical analyses.

Precautions described above were taken to avoid contamination of the samples from engine exhaust, atmospheric particulates, and rain. A double volume sample was collected at five stations for duplicate chemical analyses. All samples were labeled and double-checked for station, stratum, and sample codes; sampling date; sampling time; and type of analysis to be performed.

Samples for chemical and toxicity tests were stored on deck in sealed containers placed in insulated coolers filled with ice. These samples were off-loaded from the research vessel every 1-3 days, and transported to the walk-in refrigerator at Ecology's headquarters building in Olympia. They were held there at 4°C until shipped on ice by overnight courier to either the NOAA contractors for toxicity tests or the Manchester Environmental Laboratory for chemical analyses. Chain of custody forms accompanied all sample shipments. After a minimum of 24 hours following collection and fixation, the benthic samples were rescreened (i.e., removed from formalin) and exchanged into 70% ethanol.

Laboratory Analyses

Toxicity Testing

Multiple toxicity tests were performed on aliquots of each sample to provide a weight of evidence. Tests were selected for which there were widely accepted protocols that would represent the toxicological conditions within different phases (partitions) of the sediments. The tests included those for amphipod survival in solid-phase (bulk) sediments, sea urchin fertilization success in pore waters, and microbial bioluminescence activity and cytochrome P450 HRGS induction in an organic solvent extract. Test endpoints, therefore, ranged from survival to level of physiological activity. These four tests had been used previously in numerous sediment quality assessments conducted by NOAA nationwide (Long et al., 1996; Anderson et al., 1999a) and, therefore, did not necessarily comply with those mandated for use in Puget Sound regulatory actions. Statistical analyses applied to the data collected in 1999 were the same as those used in the reports prepared for the data collected in 1997 and 1998. The same methods were used to ensure consistency in the interpretation of data for all regions of the Sound and for other areas surveyed by NOAA nationwide.

Amphipod Survival - Solid Phase

The amphipod tests are the most widely and frequently used assays in sediment evaluations performed in North America. They are performed with test crustaceans exposed to relatively unaltered bulk sediments. *Ampelisca abdita* has shown relatively little sensitivity to nuisance factors such as grain size, ammonia, and organic carbon in previous surveys. In surveys performed by the NS&T Program (Long et al., 1996), this test has provided wide ranges in responses among samples, strong statistical associations with elevated toxicant levels, and small within-sample variability.

Ampelisca abdita is a euryhaline benthic amphipod that ranges from Newfoundland to south-central Florida, and along the eastern Gulf of Mexico. Also, it is abundant in San Francisco Bay along the Pacific coast. The amphipod test with *A. abdita* has been routinely used for sediment toxicity tests in support of numerous EPA programs, including the Environmental Monitoring and Assessment Program (EMAP) in the Virginian, Louisianian, Californian, and Carolinian provinces (Schimmel et al., 1994).

Amphipod survival tests were conducted by ToxScan, Inc., Watsonville, CA. All tests were initiated within 10 days of the date samples were collected. Samples were shipped by overnight courier in one-gallon high-density polyethylene jugs which had been washed, acid-stripped, and rinsed with de-ionized water. Sample jugs were packed in shipping coolers with blue ice. Each was inspected to ensure they were within acceptable temperature limits upon arrival and stored at 4°C until testing was initiated. Prior to testing, sediments were mixed with a stainless steel paddle and press-sieved through a 1.0 mm mesh sieve to remove debris, stones, resident biota, etc.

Amphipods were collected by SAIC from tidal flats in the Pettaquamscutt (Narrow) River, a small estuary flowing into Narragansett Bay, RI. Animals were held in the laboratory in pre-sieved uncontaminated ("home") sediments under static conditions. Fifty percent of the water in the holding containers was replaced every second day when the amphipods were fed. During holding, *A. abdita* were fed laboratory-cultured diatoms (*Phaeodactylum tricornutum*). Negative control sediments were collected by SAIC from the Central Long Island Sound (CLIS) reference station of the U.S Army Corps of Engineers, New England Division. These sediments have been tested repeatedly with the amphipod survival test and other assays and found to be non-toxic (amphipod survival has exceeded 90% in 85% of the tests) and un-contaminated (Long et al., 1996). Sub-samples of the CLIS sediments were tested along with each series of samples from northern Puget Sound.

Amphipod testing followed the procedures detailed in the Standard Guide for conducting 10 day Static Sediment Toxicity Tests with Marine and Estuarine Amphipods (ASTM, 1993). Briefly, amphipods were exposed to test and negative control sediments for 10 days with 5 replicates of 20 animals each under static conditions using filtered seawater. Aliquots of 200 ml of test or control sediments were placed in the bottom of the one-liter test chambers, and covered with approximately 600 ml of filtered seawater (28-30 ppt). Air was provided by air pumps and delivered into the water column through a pipette to ensure acceptable oxygen concentrations, but suspended in a manner to ensure that the sediments would not be disturbed.

Temperature was maintained at ~20°C by a temperature-controlled water bath. Lighting was continuous during the 10-day exposure period to inhibit the swimming behavior of the amphipods. Constant light inhibits emergence of the organisms from the sediment, thereby maximizing the amphipod's exposure to the test sediments. Information on temperature, salinity, dissolved oxygen, pH and ammonia in test chambers was obtained during tests of each batch of samples to ensure compliance within acceptable ranges. Ammonia concentrations were determined in both pore waters (day 0 of the tests) and overlying waters (days 2 and 8 of the tests). Concentrations of the un-ionized form of ammonia were calculated, based upon measures of total ammonia, and concurrent measures of pH, salinity and temperature.

Twenty healthy, active animals were placed into each test chamber, and monitored to ensure they burrowed into sediments. Non-burrowing animals were replaced, and the test initiated. The jars were checked daily, and records were kept of animals that had died, were on the water surface, had emerged on the sediment surface, or were in the water column. Animals on the water surface were gently freed from the surface film to enable them to burrow, and dead amphipods were removed.

Tests were terminated after ten days. Contents of each of the test chambers were sieved through a 0.5 mm mesh screen. The animals and any other material retained on the screen were examined under a stereomicroscope for the presence of amphipods. Total amphipod mortality was recorded for each test replicate.

A positive control (reference toxicant) test was used to document the sensitivity of each batch of test organisms. The positive control consisted of 96 hr water-only exposures to sodium dodecyl sulfate (SDS). The LC50 (lethal concentration for 50% of the test animals) values were calculated for each test run with results from tests of five SDS concentrations.

Sea Urchin Fertilization - Pore Water

Tests of sea urchin fertilization have been used in assessments of ambient water and effluents and in previous NS&T Program surveys of sediment toxicity (Long et al., 1996). Test results have shown wide ranges in responses among test samples, excellent within-sample homogeneity, and strong associations with the concentrations of toxicants in the sediments. This test combines the features of testing sediment pore waters (the phase of sediments in which dissolved toxicants are highly bioavailable) and exposures to early life stages of invertebrates (sperm cells) which often are more sensitive than adult forms. Tests of sediment pore water toxicity were conducted with the Pacific coast purple urchin *Strongylocentrotus purpuratus* by the U.S. Geological Survey laboratory in Corpus Christi, Texas.

Sediments from each sampling location were shipped by overnight courier in one-gallon high-density polyethylene jugs chilled in insulated coolers packed with blue ice. Upon arrival at the laboratory, samples were either refrigerated at 4°C or processed immediately. All samples were processed (i.e., pore waters extracted) within 10 days of the sampling date.

Pore waters were extracted within ten days of the date of collection, usually within 2-4 days. Pore water was extracted from sediments with a pressurized squeeze extraction device (Carr and Chapman, 1995). After extraction, pore water samples were centrifuged in polycarbonate bottles (at 1200 G for 20 minutes) to remove any particulate matter. The supernatant was then frozen at -20°C. Two days before the start of a toxicity test, samples were moved from a freezer to a refrigerator at 4°C, and one day prior to testing, thawed in a tepid (20°C) water bath. Experiments performed by USGS have demonstrated no effects upon toxicity attributable to freezing and thawing of the pore water samples (Carr and Chapman, 1995).

Tests followed the methods of Carr and Chapman (1995); Carr et al. (1996a,b); Carr (1998) and USGS SOP F10.6, developed initially for *Arbacia punctulata*, but adapted for use with *S. purpuratus*. Unlike *A. punctulata*, adult *S. purpuratus* cannot be induced to spawn with electric stimulus. Therefore, spawning was induced by injecting 1-3 ml of 0.5 M potassium chloride into the coelomic cavity. Tests with *S. purpuratus* were conducted at 15°C; test temperatures were maintained by incubation of the pore waters, the dilution waters and the tests themselves in an environmental chamber. Adult *S. purpuratus* were obtained from Marinus Corporation, Long Beach, CA. Pore water from sediments collected in Redfish Bay, Texas, an area located near the testing facility, was used as negative controls. Sediment pore waters from this location have been determined repeatedly to be non-toxic in this test in many trials (Long et al., 1996). Each of the pore water samples was tested in a dilution series of 100%, 50%, and 25% of the water quality (salinity)-adjusted sample with 5 replicates per treatment. Dilutions were made with clean, filtered (0.45 *u*m), Port Aransas laboratory seawater, which has been shown in many previous trials to be non-toxic. A dilution series test with SDS was included as a positive control.

Sample temperatures were maintained at 20±1°C. Sample salinity was measured and adjusted to 30±1 ppt, if necessary, using purified deionized water or concentrated brine. Other water quality measurements were made for dissolved oxygen, pH, sulfide and total ammonia. Temperature and dissolved oxygen were measured with YSI meters; salinity was measured with Reichert or American Optical refractometers; pH, sulfide and total ammonia (expressed as total ammonia nitrogen, TAN) were measured with Orion meters and their respective probes. The concentrations of un-ionized ammonia (UAN) were calculated using respective TAN, salinity, temperature, and pH values.

For the sea urchin fertilization test, the samples were cooled to 15±1°C. Fifty µl of appropriately diluted sperm were added to each vial, and incubated at 15±1°C for 30 minutes. One ml of a well-mixed dilute egg suspension was added to each vial, and incubated an additional 30 minutes at 15± 2°C. Two ml of a 10% solution of buffered formalin was added to stop the test. Fertilization membranes were counted, and fertilization percentages calculated for each replicate test.

The relative sensitivities of *S. purpuratus* and *A. punctulata* were determined as a part of the 1997 northern Puget Sound survey (Long et al., 1999a). A series of five reference toxicant tests were performed with both species. Tests were conducted with copper sulfate, PCB aroclor 1254, o,p'-DDD, phenanthrene, and naphthalene in seawater. The data indicated that the two species generally were similar in their sensitivities to the five selected chemicals.

Microbial Bioluminescence (Microtox™) - Organic Solvent Extract

This is a test of the relative toxicity of extracts of the sediments prepared with an organic solvent, and, therefore, it is unaffected by the effects of environmental factors, such as grain size, ammonia and organic carbon. Organic toxicants, and to a lesser degree trace metals, that may or may not be readily bioavailable are extracted with the organic solvent. Therefore, this test can be considered as indicative of the potential toxicity of mixtures of substances bound to the sediment matrices. In previous NS&T Program surveys, the results of Microtox™ tests have shown extremely high correlations with the concentrations of mixtures of organic chemicals. Microtox™ tests were run by the U. S. Geological Survey Laboratory in Columbia, MO, on extracts prepared by Columbia Analytical Services (CAS) in Kelso, WA.

The Microtox™ assay was performed with dichloromethane (DCM) extracts of sediments following the basic procedures used in testing Puget Sound sediments (PSEP, 1995) and Pensacola Bay sediments (Johnson and Long, 1998). All sediment samples were stored in the dark at 4°C for 5-10 days before processing was initiated. A 3-4 g sediment sample from each station was weighed, recorded, and placed into a DCM-rinsed 50 ml centrifuge tube. A 15 g portion of sodium sulfate was added to each sample and mixed. Pesticide grade DCM (30 ml) was added and mixed. The mixture was shaken for 10 seconds, vented and tumbled overnight.

Sediment samples were allowed to warm to room temperature and the overlying water discarded. Samples were then homogenized with a stainless steel spatula, and 15-25 g of sediment were transferred to a centrifuge tube. The tubes were spun at 1000 G for 5 minutes and the pore water was removed using a Pasteur pipette. Three replicate 3-4 g sediment subsamples from each station were placed in mortars containing a 15g portion of sodium sulfate and mixed. After 30 minutes, subsamples were ground with a pestle until dry. Subsamples were added to 50 ml centrifuge tubes and 30 ml of DCM were added to each tube and shaken to dislodge sediments. Tubes were shaken overnight on an orbital shaker at a moderate speed and then centrifuged at 500 G for 5 min and the sediment extracts transferred to Turbovap™ tubes. Then, 20 ml of DCM was added to sediment, shaken by hand for 10 seconds and spun at 500 g for 5 minutes. The previous step was repeated once more and all three extracts were combined in the Turbovap™ tube. Sample extracts were then placed in the Turbovap™ and reduced to a volume of 0.5 ml. The sides of the Turbovap™ tubes were rinsed down with methylene chloride and again reduced to 0.5 ml. Then, 2.5 ml of dimethylsulfoxide (DMSO) were added to the tubes that were returned to the Turbovap™ for an additional 15 minutes. Sample extracts were placed in clean vials and 2.5 ml of DMSO were added to obtain a final volume of 5 ml DMSO. Because organic sediment extracts were obtained with DCM, a strong non-polar solvent, the final extract was evaporated and redissolved in DMSO. The DMSO was compatible with the Microtox™ system because of its low test toxicity and good solubility with a broad spectrum of apolar chemicals (Johnson and Long, 1998).

A suspension of luminescent bacteria, *Vibrio fischeri* (Azur Environmental, Inc.), was thawed and hydrated with toxicant-free distilled water, covered and stored in a 4°C well on the Microtox™ analyzer. An aliquot of 10 µl of the bacterial suspension was transferred to a test vial containing the standard diluent (2% sodium chloride (NaCl)) and equilibrated to 15°C using a temperature-controlled photometer. The amount of light lost per sample was assumed to be proportional to the toxicity of that test sample. To determine toxicity, each sample was diluted into four test concentrations. Percent decrease in luminescence of each cuvette relative to the reagent blank was calculated. Light loss was expressed as a gamma value and defined as the ratio of light lost to light remaining. The log of gamma values from these four dilutions was plotted and compared with the log of the samples' concentrations. The concentrations of the extract that inhibited luminescence by 50% after a 5-min exposure period, the EC50 value, was determined and expressed as mg equivalent sediment wet weight. Data were reduced using the Microtox™ Data Reduction software package. All EC50 values were average 5 minute readings with 95% confidence intervals for three replicates.

A negative control (extraction blank) was prepared using DMSO, the test carrier solvent. A phenol standard (45mg/l phenol) was run after re-constitution of each vial of freeze-dried *V. fischeri*. Tests of extracts of sediments from the Redfish Bay, TX site used in the urchin tests also were used as negative controls in the Microtox™ tests.

Human Reporter Gene System (Cytochrome P450) Response - Organic Solvent Extract

Sediment samples were also analyzed with the Human Reporter Gene System (cytochrome P450) response assay (P450 HRGS). The test uses a transgenic cell line (101L), derived from the human hepatoma cell line (HepG2), in which the flanking sequences of the CYP1A gene, containing the xenobiotic response elements (XREs), have been stably linked to the firefly luciferase gene (Anderson et al. 1995, 1996). As a result, the enzyme luciferase is produced in the presence of chemicals that bind the XREs. This test is used to determine the presence of organic chemicals that bind to the Ah (aryl hydrocarbon) receptor and induce the CYP1A locus on the vertebrate chromosome. Under appropriate test conditions, induction of CYP1A is evidence that the cells have been exposed to one or more of these xenobiotic organic chemicals, including dioxins, furans, planar PCBs, and several polycyclic aromatic hydrocarbons (Jones and Anderson, 1999). Differences in the ability of the P450 enzyme to metabolize chlorinated and non-chlorinated chemicals allow for differentiation between these classes of chemicals in environmental samples. Since most PAHs are rapidly metabolized, they exhibit a maximum response in 6 hours, at which point the response begins to fade. Chlorinated hydrocarbons (dioxins, furans, and certain PCBs), on the other hand, do not show a maximum response until 16 hours after exposure (Jones and Anderson, 2000). The P450 HRGS assay provides an estimate of the presence of contaminants bound to sediment that could produce chronic and/or carcinogenic effects in benthic biota and/or demersal fishes that feed in sediments. These tests were run by the Columbia Analytical Services, Inc. in Vista, CA with solvent extracts prepared by their laboratory in Kelso, WA. The details of this test are provided as U.S. EPA Method 4425 (EPA, 1999), Standard Method 8070 by the American Public Health Association (APHA, 1998), and ASTM method E 1853M-98 by the American Society for Testing and Material (ASTM, 1999).

After removal of debris and pebbles, the sediment sample was homogenized, dried with anhydrous sodium sulfate, and 20 g of sediment was extracted by sonication with dichloromethane (DCM), also known as methylene chloride. The extract was carefully evaporated and concentrated under a flow of nitrogen, and exchanged into a mixture of dimethylsulfoxide (DMSO), toluene and isopropyl alcohol (2:1:1) to achieve a final volume of 2 mL. The 2 mL extracts were split into two 1 mL vials for testing with the Microtox™ and P450 HRGS assays. The extraction procedure is well suited for extraction of neutral, non-ionic organic chemicals, such as aromatic and chlorinated hydrocarbons. Extraction of other classes of toxicants, such as metals and polar organic chemicals, is not efficient. DMSO is compatible with these tests because of its low toxicity and high solubility with a broad spectrum of non-polar chemicals.

Briefly, a small amount of organic extract of sediment (up to 20 μL), was applied to approximately one million cells in each well of a 6-well plate with 2 mL of medium. Detection of enzyme induction in this assay was relatively rapid and simple to measure since binding of a xenobiotic with the Ah receptor results in the production of luciferase.

After 16 hours of incubation with the extract, the cells were washed and lysed. Cell lysates were centrifuged, and the supernatant was mixed with buffering chemicals. Enzyme reaction was initiated by injection of luciferin. The resulting luminescence was measured with a luminometer and was expressed in relative light units (RLUs). A solvent blank (using a volume of solvent equal to the sample's volume being tested) and reference toxicants (TCDD, dioxin/furan mixture, B[a]P) were used with each batch of samples.

Mean RLU, standard deviation, and coefficient of variation of replicate analyses of each test solution were recorded. Enzyme fold induction (times background) was calculated as the mean RLU of the test solution divided by the mean RLU of the solvent blank. From the standard concentration-response curve for benzo[a]pyrene (B[a]P), the HRGS response to 1 μg/mL was approximately 60. Data were converted to μg of B[a]P equivalents per g of sediment by considering the dry weight of the samples, the volume of solvent, the amount added to the well, and the factor of 60 for B[a]P. If 20 μL of the 2 mL extracts were used, then fold induction was multiplied by the volume factor of 100 and divided by 60 times the dry weight. Since testing at only one time interval (16 h) was not allowed discrimination between PAHs and chlorinated hydrocarbons, the data were also expressed as Toxic Equivalents (TEQs). Based on a standard curve with a dioxin/furan mixture, fold induction was equal to the TEQ (in pg/mL). Therefore, fold induction was multiplied by the volume factor (e.g., 100), and divided by the dry weight times 1000 to convert pg to the TEQ in ng/g.

Quality control tests were run with clean extracts spiked with tetrachlorodibenzo-p-dioxin (TCDD) and B[a]P to ensure compliance with results of previous tests. From a long-term control chart, the running average fold induction for 1 ng/mL of dioxin was approximately 105, and fold induction for 1 μg/mL of B[a]P was 60. Tests were rerun if the coefficient of variation for replicates was greater than 20%, and if fold induction was over the linear range (100 fold). HRGS tests performed on extracts from Redfish Bay, Texas, were used as a negative control.

For a given study area, the B[a]P equivalent data were used to calculate the mean, standard deviation and 99% confidence interval for all samples (Anderson et al., 1999a). Samples above the 99% confidence interval were generally considered to pose some chronic threat to benthic organisms. The values from one investigation were compared to the overall database to evaluate the magnitude of observed concentration. From analysis of the database, values less than 11 μg/g B[a]P equivalents (B[a]PEq) were not likely to produce adverse effects, while impacts were uncertain between 11 and 37 μg B[a]PEq/g. Moderate effects were expected at 37 μg/g, and sediment with over 60 μg B[a]PEq/g have been shown to be highly correlated with degraded benthic communities (Fairey, et al., 1996). Previous studies have shown a high correlation of the HRGS responses in extracts of sediments and tissues to the content of PAHs in the samples (Anderson et al. 1999a, 1999b).

Chemical Analyses

Laboratory analyses were performed for 158 parameters and chemical chemicals (Table 2), including 133 trace metals, pesticides, hydrocarbons and selected normalizers (i.e., grain size, total organic carbon) that are routinely quantified by the NS&T Program. An additional 20 chemicals were required by Ecology to ensure comparability with previous PSAMP and enforcement studies. Five additional chemicals were automatically quantified by Manchester Environmental Laboratory during analysis for the required chemicals. Analytical procedures provided performance equivalent to those of the NS&T Program and the PSEP Protocols, including those for analyses of blanks and standard reference materials. Information was reported on recovery of spiked blanks, analytical precision with standard reference materials, and duplicate analyses of every 20th sample. Practical Quantitation Limits were reported for chemicals that were at or below the detection limits and qualified with as undetected.

The laboratory analytical methods and reporting limits for quantitation of the 158 chemistry parameters analyzed for are summarized in Table 3 and described in detail below. Methods and resolution levels for field collection of temperature and salinity are included in Table 4.

Grain Size

Analysis for grain size was performed according to the PSEP Protocols (PSEP, 1986). The PSEP grain size method is a sieve-pipette method. In this method, the sample is passed through a series of progressively smaller sieves, with each fraction being weighed. After this separation, the very fine material remaining is placed into a column of water, and allowed to settle. Aliquots are removed at measured intervals, and the amount of material in each settling fraction is measured. Analysis of this parameter was contracted by MEL to Rosa Environmental and Geotechnical Laboratory, LLC, Seattle, Washington.

Total Organic Carbon (TOC)

Total organic carbon analysis was performed according to PSEP Protocols (PSEP, 1986). The method involves drying sediment material, pretreatment and subsequent oxidation of the dried sediment, and determination of CO_2 by infra-red spectroscopy.

Metals

To maintain compatibility with previous PSAMP metals data, EPA Methods 3050/6010 were used for the determination of metals in sediment. Method 3050 is a strong acid (aqua regia) digest that has been used for the last several years by Ecology for the characterization of sediments for trace metal contamination. Method 3050 is also the recommended digestion technique for digestion of sediments in the recently revised PSEP protocols (PSEP, 1996c). This digestion does not yield geologic (total) recoveries for most analytes including silicon, iron, aluminum and manganese. It does, however, account for the deposition and presence of metals in sediments that have resulted from anthropogenic sources.

For comparison with NOAA's national bioeffects survey's existing database, Manchester simultaneously performed a total (hydrofluoric acid-based) digestion (EPA method 3052) on portions of the same samples. Determination of metals values for both sets of extracts were made via ICP, ICP-MS, or GFAA, using a variety of EPA methods (Table 3) depending upon the appropriateness of the technique for each analyte.

Mercury

Mercury was determined by USEPA Method 245.5, mercury in sediment, by cold vapor atomic absorption (CVAA). The method consists of a strong acid sediment digestion, followed by reduction of ionic mercury to Hg^0, and analysis of mercury by cold vapor atomic absorption. This method is recommended by the PSEP Protocols (PSEP, 1996c) for the determination of mercury in Puget Sound sediment.

Butyl Tins

Butyl tins in sediments were analyzed by the Manchester method (Manchester Environmental Laboratory, 1997). This method consists of solvent extraction of sediment, derivitization of the extract with the Grignard reagent hexylmagnesium bromide, cleanup with silica and alumina, and analysis by Atomic Emission Detector (AED).

Base/Neutral/Acid (BNA) Organic Chemicals

USEPA Method 846 8270, a recommended PSEP method (PSEP, 1996d), was used for semi-volatile analysis. This is a capillary column, GC/MS method.

Polynuclear Aromatic Hydrocarbons (PAH) (extended list)

At NOAA's request, the extended analyte list was modified by the inclusion of additional PAH chemicals. The PAH analytes were extracted separately using the EPA method SW846 3545. This method uses a capillary column GC/MS system set up in selective ion monitoring (SIM) mode to quantify PAHs. Quantitation is performed using an isotopic dilution method modeled after USEPA Method SW 846 8270, referenced in PSEP, 1996d.

Chlorinated Pesticides and Polychlorinated Biphenyl (PCB) Aroclors

EPA Method 8081 for chlorinated pesticides and PCB was used for the analysis of these chemicals. This method is a GC method with dual dissimilar column confirmation. Electron capture detectors were used.

PCB Congeners

PCB methodology was based on the NOAA congener methods detailed in Volume IV of the NS&T Sampling and Analytical Methods documents (Lauenstein and Cantillo, 1993). The concentrations of the standard NOAA list of 20 congeners were determined.

Benthic Community Analyses

Sample Processing and Sorting

All methods, procedures, and documentation (chain-of-custody forms, tracking logs, and data sheets) were similar to those described for the PSEP (1987) and in the PSAMP Marine Sediment Monitoring Component – Final Quality Assurance Project and Implementation Plan (Dutch et al., 1998).

Upon completion of field collection, benthic infaunal samples were checked into the benthic laboratory at Ecology's headquarters building. After a minimum fixation period of 24 hours (and maximum of 7-10 days), the samples were washed on sieves to remove the formalin (1.0 mm fraction on a 0.5 mm sieve, 0.5 mm fraction on a 0.25 mm sieve) and transferred to 70% ethanol. Sorting and taxonomic identification of the 0.5 mm fraction were completed separately by a NOAA contractor outside of the scope of work of this effort. The results of these separate analyses will be reported elsewhere by NOAA. After staining with rose bengal, the 1.0 mm sample fractions were examined under dissection microscopes, and all macroinfaunal invertebrates and fragments were removed and sorted into the following major taxonomic groups: Annelida, Arthropoda, Mollusca, Echinodermata, and miscellaneous taxa. Meiofaunal organisms such as nematodes and foraminiferans were not removed from samples, although their presence and relative abundance were recorded. Representative samples of colonial organisms such as hydrozoans, sponges, and bryozoans were collected, and their relative abundance noted. Sorting QA/QC procedures consisted of resorting 25% of each sample by a second sorter to determine whether a sample sorting efficiency of 95% removal was met. If the 95% removal criterion was not met, the entire sample was resorted.

Taxonomic Identification

Upon completion of sorting and sorting QA/QC, the majority of the taxonomic work was contracted to recognized regional taxonomic specialists. Organisms were enumerated and identified to the lowest taxonomic level possible, generally to species. In general, anterior ends of organisms were counted, except for bivalves (hinges), gastropods (opercula), and ophiuroids (oral disks). When possible, at least two scientific references (preferably including original descriptions) were used for each species identification. A maximum of three representative organisms of each species or taxon was removed from the samples and placed in a voucher collection, housed at the Ecology headquarters building in Lacey, WA. Taxonomic identification quality control for all taxonomists included re-identification of 5% of all samples identified by the primary taxonomist and verification of voucher specimens generated by another qualified taxonomist.

Data Summary, Display, and Statistical Analysis

Toxicity Testing

Amphipod Survival – Solid Phase

Data from each station in which mean percent survival was less than that of the control were compared to the CLIS control using a one-way, unpaired t-test (alpha < 0.05) assuming unequal variance. Results were not transformed because examination of data from previous tests has shown that results of tests performed with *A. abdita* met the requirements for normality.

"Significant toxicity" for *A. abdita* is defined here as survival statistically less than that in the performance control (alpha < 0.05). In addition, samples in which survival was significantly less than controls and less than 80% of CLIS control values were regarded as "highly toxic". The 80% criterion is based upon statistical power curves created from SAIC's extensive database with *A. abdita* (Thursby et al., 1997). Their analyses showed that the power to detect a 20% difference from the control is approximately 90%. The minimum significant difference (i.e., "MSD" of <80% of control response) was used as the critical value in calculations of the spatial extent of toxicity (Long et al., 1996, 1999a).

Sea Urchin Fertilization - Pore Water

For the sea urchin fertilization tests, statistical comparisons among treatments were made using ANOVA and Dunnett's one-tailed *t*-test (which controls the experiment-wise error rate) on the arcsine square root transformed data with the aid of SAS (SAS, 1989). The trimmed Spearman-Karber method (Hamilton et al., 1977) with Abbott's correction (Morgan, 1992) was used to calculate EC50 (50% effective concentration) values for dilution series tests. Prior to statistical analyses, the transformed data sets were screened for outliers (Moser and Stevens, 1992). Outliers were detected by comparing the studentized residuals to a critical value from a t-distribution chosen using a Bonferroni-type adjustment. The adjustment is based on the number of observations (n) so that the overall probability of a type 1 error is at most 5%. The critical value (CV) is given by the following equation: $cv= t(df_{Error}, .05/[2 \times n])$. After omitting outliers but prior to further analyses, the transformed data sets were tested for normality and for homogeneity of variance using SAS/LAB Software (SAS, 1992). Statistical comparisons were made with mean results from the Redfish Bay controls. Reference toxicant concentration results were compared to filtered seawater controls and each other using both Dunnett's t-test and Duncan's multiple range test to determine lowest observable effects concentrations (LOECs) and no observable effects concentrations (NOECs).

In addition to the Dunnett's one-tailed t-tests, data from field-collected samples were treated with an analysis similar to the MSD analysis used in the amphipod tests. Power analyses of the sea urchin fertilization data for A. punctulata have shown MSDs of 15.5% for alpha <0.05 and 19% for alpha <0.01. The 90th percentile MSD calculated for S. purpuratus fertilization was 88% of control response (Phillips et al., 2001). However, to be consistent with the statistical methods used in previous surveys (Long et al., 1996, 1999a), estimates of the spatial extent of toxicity were based upon the same critical value used in the amphipod tests (i.e., <80% of control response).

Microbial Bioluminescence (Microtox™) - Organic Solvent Extract

Microtox™ data were analyzed using the computer software package developed by Microbics Corporation to determine concentrations of the extract that inhibit luminescence by 50% (EC50). This value was then converted to mg dry weight using the calculated dry weight of sediment present in the original extract. To determine significant differences of samples from each station, pair-wise comparisons were made between survey samples and results from Redfish Bay control sediments using analysis of variance (ANOVA). Concentrations tested were expressed as mg dry weight based on the percentage extract in the 1 ml exposure volume and the calculated dry weight of the extracted sediment. Statistical comparisons among treatments were made using ANOVA and Dunnett's one-tailed t-tests on the log transformed data with the aid of SAS (SAS, 1989).

Three critical values were used to estimate the spatial extent of toxicity in these tests. First, a value of <80% of Redfish Bay controls (equal to 8.5 mg/ml) was used; i.e., equivalent to the values used with the amphipod and urchin tests. Second and third, values of <0.51 mg/ml and <0.06 mg/ml calculated in the 1997 northern Puget Sound study were used, based upon the frequency distribution of Microtox™ data from NOAA's surveys nationwide (as per Long et al., 1999a).

Human Reporter Gene System (Cytochrome P450) Response - Organic Solvent Extract

Microsoft Excel 5.0 was used to determine the mean HRGS response and the 99% confidence interval of the B[a]P equivalent values for all 100 samples. Mean responses determined for all 100 samples were compared to the upper prediction limits calculated in the 1997 northern Puget Sound study (Long et al., 1999a): >11.1 μg/g and >37.1 μg/g. The value of 11.1 μg/g was viewed as the upper end of the range in background values in this test, while the value of 37.1 μg/g was viewed as the threshold for elevated, possibly biological relevant, concentrations.

Incidence and Severity, Spatial Patterns and Gradients, and Spatial Extent of Sediment Toxicity

The incidence of toxicity was determined by dividing the numbers of samples identified as either significantly different from controls (i.e., "significantly toxic") or significantly different from controls and <80% of control response (i.e., "highly toxic") by the total number of samples tested (i.e., 100). Severity of the responses was determined by examining the range in responses for each of the tests and identifying those samples with the highest and lowest responses. Spatial patterns in toxicity were illustrated by plotting the results for each sampling station as symbols or histograms on base maps of each major region.

Estimates of the spatial extent of toxicity were determined with cumulative distribution functions in which the toxicity results from each station were weighted to the dimensions (km^2) of the sampling stratum in which the samples were collected (Schimmel et al., 1994). The size of each stratum (km^2) was determined by use of an electronic planimeter applied to navigation charts, upon which the boundaries of each stratum were outlined (Table 1). Stratum sizes were calculated as the averages of three trial planimeter measurements that were all within 10% of each other. A critical value of less than 80% of control response was used in the calculations of the spatial extent of toxicity for all tests except the cytochrome P450 HRGS assay. That is, the sample-weighted sizes of each stratum in which toxicity test results were less than 80% of control responses were summed to estimate the spatial extent of toxicity. Additional critical values described above were applied to the Microtox™ and cytochrome P450 HRGS results.

Concordance Among Toxicity Tests

Non-parametric, Spearman-rank correlations were determined for combinations of toxicity test results to quantify the degree to which these tests showed correspondence in spatial patterns in toxicity. None of the data from the four toxicity tests were normally distributed, therefore, non-parametric tests were used on raw (i.e., nontransformed) data. Both the correlation coefficients (rho) and the probability values (p) were calculated.

Chemical Analyses

Spatial Patterns and Spatial Extent of Sediment Contamination

Chemical data from the sample analyses were plotted on base maps to identify spatial patterns, if any, in concentrations. The results were shown with symbols indicative of samples in which effects-based numerical guideline and criteria concentrations were exceeded. The spatial extent of contamination was determined with cumulative distribution functions in which the sizes of strata in which samples exceeded effects-based, sediment quality values were summed.

Three sets of chemical concentrations were used as critical values: the SQS and CSL values contained in the Washington State Sediment Management Standards (Chapter 173-204 WAC) and the Effects Range-Median (ERM) values developed by Long et al. (1995) from NOAA's national sediment data base (Appendix D). Two additional measures of chemical contamination also examined and considered for each sample were the Effects Range-Low (ERL) values developed for NOAA (Long et al., 1995), and the mean ERM quotient (Long and MacDonald, 1998). Samples with chemical concentrations greater than ERLs were viewed as slightly contaminated as opposed to those with concentrations less than or equal to the ERLs, which were viewed as uncontaminated. Mean ERM quotients were calculated as the mean of the quotients derived by dividing the chemical concentrations in the samples by their respective ERM values. The greater the mean ERM quotient, the greater the overall contamination of the sample as determined by the concentration of 25 substances. Mean ERM quotient values of 1.0 or greater, equivalent to ERM unity, were independently determined to be highly predictive of acute toxicity in amphipod survival tests (Long and MacDonald, 1998). Mean SQS and CSL quotients were determined using the same procedure. Spatial patterns in chemical concentrations were depicted on base maps using symbols to indicate stations in which any (i.e., one or more) of the SQS, CSL, or ERM vales were exceeded. The same sets of values were used to calculate the spatial extent of contamination (as area and percentage of total area). The area and percentage of area were calculated in which one or more criteria or guidelines were exceeded. Areas were not double counted when more than one chemical substance exceeded these values. The mean ERM-, SQS-, and CSL-quotients were used to identify relationships between the concentrations of mixtures of chemicals and both the degree of toxicity and possible benthic impacts.

Chemistry/Toxicity Relationships

Chemistry/toxicity relationships were determined in a multi-step sequence. First, the concentrations of different groups of chemicals were normalized to their respective ERM values (Long et al., 1995) and to their Washington State SQS and CSL values (Washington State Sediment Management Standards – Ch. 173-204 WAC), generating mean ERM, SQS, and CSL quotients. Non-parametric, Spearman-rank correlations were then used to determine if there were relationships between the four measures of toxicity and these normalized mean values generated for the different groups of chemical chemicals.

Second, Spearman-rank correlations were also used to determine relationships between each toxicity test and each physical/chemical variable. The correlation coefficients and their statistical significance (p values) were recorded and compared among chemicals to identify which chemicals co-varied with toxicity and which did not. For many of the different semivolatile organic substances in the sediments, correlations were conducted for all 100 samples, using the limits of quantitation for values reported as undetected. If the majority of concentrations were qualified as either estimates or below quantitation limits, the correlations were run again after eliminating those samples. No analyses were performed for the numerous chemicals whose concentrations were below the limits of quantitation in all samples.

Third, for those chemicals in which a significant correlation was observed, the data were examined in scatterplots to determine whether there was a reasonable pattern of increasing toxicity with increasing chemical concentration. Also, chemical concentrations in the scatterplots were compared with the SQS, CSL, and ERM values to determine which samples, if any, were both toxic and had elevated chemical concentrations. The concentrations of un-ionized ammonia were compared to lowest observable effects concentrations (LOEC) determined for the sea urchin tests by the USGS (Carr et al., 1995) and no observable effects concentrations (NOEC) determined for amphipod survival tests (Kohn et al., 1994).

The objectives of this study did not include a determination of the cause(s) of toxicity or benthic alterations. Such determinations would require the performance of toxicity identification evaluations and other similar research. The purpose of the multi-step approach used in the study was to identify which chemicals, if any, showed the strongest concordance with the measures of toxicity and benthic infaunal structure.

Correlations were determined for all the substances that were quantified, including trace metals (both total and partial digestion), metalloids, un-ionized ammonia (UAN), percent fines, total organic carbon (TOC), chlorinated organic hydrocarbons (COHs), and polynuclear aromatic hydrocarbons (PAHs). Concentrations were normalized to TOC where required for SQS and CSL values.

Those substances that showed significant correlations were indicated with asterisks (*= $p \leq 0.05$, ** = $p \leq 0.01$, ***= $p \leq 0.001$, and ****= $p \leq 0.0001$) depending upon the level of probability. A Bonferroni's adjustment was performed to account for the large number of independent variables (157 chemical chemicals). This adjustment is required to eliminate the possibility of some correlations appearing to be significant by random chance alone.

Benthic Community Analyses

All benthic infaunal data were reviewed and standardized for any taxonomic nomenclatural inconsistencies by Ecology personnel using an internally developed standardization process. With assistance from the taxonomists, the final species list was also reexamined for identification and removal of taxa that were non-countable infauna (Appendix E). This included (1) organisms recorded with presence/absence data, such as colonial species, (2) meiofaunal organisms, and (3) incidental taxa that were caught by the grab, but are not a part of the infauna (e.g., planktonic forms).

A series of benthic infaunal indices were then calculated to summarize the raw data and characterize the infaunal invertebrate assemblages identified from each station. Indices were based upon all countable infaunal taxa only. Five indices were calculated, including total abundance, major taxa abundance, taxa richness, Pielou's evenness (J'), and Swartz's Dominance Index (SDI). These indices are defined in Table 5.

Benthic Community/Chemistry and Benthic Community/Toxicity Analyses

Nonparametric Spearman-rank correlation analyses were conducted among all benthic indices, chemistry, and toxicity data. The correlation coefficients (rho values) and their statistical significance (p values) were recorded and examined to identify which benthic indices co-varied with toxicity results and chemistry concentrations. Comparisons were made to determine similarities between these correlation results and those generated for the chemistry/toxicity correlation analyses.

Sediment Quality Triad Analyses

Following the suggestions of Chapman (1996), data from the chemical analyses, toxicity tests, and benthic analyses were compiled to identify the sampling locations with the highest and lowest overall sediment quality and samples with mixed or intermediate results. The percent spatial extent of sediment quality was computed for stations with four combinations of chemical/toxicity/benthic results. Highest quality sediments were those in which no chemical concentrations exceeded numerical guidelines or criteria, toxicity was not apparent in any of the tests, and the benthos included relatively large numbers of organisms and species, and pollution-sensitive species were present. Lowest quality sediments were those with chemical concentrations greater than any of the sediment quality values (i.e., ERM, SQS, or CSL), toxicity in at least one of the tests, and a relatively depauperate benthos or a large number of pollution-tolerant species were present. Two intermediate categories of sediment quality were also identified, including sediments with one of the three parameters (i.e., chemistry, toxicity, or benthos) displaying degraded conditions; and sediments with two of the three parameters indicating degraded conditions.

The benthic data analyses and interpretations presented in this report were intended to be preliminary and general. Estimates of the spatial extent of benthic alterations are not made due to the lack of widely accepted critical values for calculated benthic indices at this time. A more thorough examination of the benthic infauna communities in central Puget Sound and their relationship to sediment characteristics, toxicity, and chemistry will be presented in future reports. Conclusions drawn from these data were a function, in part, of the sampling design selected for the study, the types of laboratory tests and analyses that were selected, and the types of statistical analyses that were applied to the data. Obviously, other conclusion may have been formed I other procedures and methods had been used in the survey.

Results

A record of all field notes and observations made for each sediment sample collected is presented in Appendix F. The results of the toxicity testing, chemical analyses, and benthic infaunal abundance determination are reported in various summarized tables in this section of the report and in the appendices. Due to the large volume of data generated, some raw data have not been included in this report. All raw data can be obtained from Ecology's Sediment Monitoring Team database or Ecology's Sediment Management Unit SEDQUAL database. The web site addresses linking to both these databases are located on the inside cover of this report.

Toxicity Testing

Incidence and Severity of Toxicity

Amphipod Survival - Solid Phase

Amphipod survival tests were run in 11 batches corresponding to the shipments that were received from the field crew. Sample storage times were less than 10 days in all cases. Measures of test water pH, dissolved oxygen, temperature, and ammonia were within acceptable limits in all but a few samples. In a few samples the concentrations of un-ionized ammonia were slightly elevated above toxicity thresholds, but amphipod survival was not significantly different from controls in these samples. The mean LC50 concentration in 12 tests of sodium dodecyl sulfate (SDS) in water was 10.49mg/L. LC50s for 9 of 12 tests were within the warning limits of two standard deviations of the historical mean (i.e., 8.24 to 12.73 mg/L). Two LC50s were between the warning limits and control limits (5.99 to 14.98 mg/L) and one LC50 was outside the controls limit (LC50 of 15.78mg/L in test number 2). Toxicity in test samples was not attributable to poor animal viability.

Mean performance control survival ranged from 81% to 98% in the 11 test batches. Because of relatively low survival in four test runs (81%, 87%, 90%, and 90%), some samples were re-tested in four additional batches. During the summer of 1999, severe drought and high temperatures may have caused native amphipods in Narragansett Bay to experience high degrees of heat-related stress. These conditions were observed and reported by many other investigators and laboratories during the same time period. Survival in the negative controls in the re-tested batches always improved to ≥ 87% and all of the samples that were re-tested invariably were non-toxic. Overall, the results of these tests were accepted and treated as reliable data.

Results of the amphipod survival tests for the 100 southern Puget Sound sediment samples are reported in Table 6. Mean survival in the 100 test samples ranged from 77% to 99%. When expressed as percentages of control survival, the results ranged from 81% to >100%. Mean survival among samples collected within each stratum was not significantly lower than in controls. Survival in three samples (those from stations 245 (Pickering Passage/Squaxin Island), 254 (Nisqually Reach), and 294 (Thea Foss Waterway)) was statistically different from mean control survival (i.e., the response was statistically significant in 3 samples) however, control-adjusted survival invariably exceeded 80% (i.e., the incidence of "highly toxic" samples in this study was 0%). Control-adjusted survival was 81%, 92%, and 90% respectively in the batches of test samples in which statistically significant responses were recorded. The incidence of statistically significant toxicity in these samples (3%) was lower than observed in central Puget Sound in 1998 (7%) and in northern Puget Sound in 1997 (13%). Overall, the combined incidence of significant toxicity was 7.7% (23 of 300 samples). Only one sample (i.e., 0.3%) from the 300 samples tested throughout Puget Sound (station 167, Port Washington Narrows) indicated "highly toxic" characteristics.

Sea Urchin Fertilization – Pore Water

Porewater tests were run in two batches, consisting of samples from stations 206-253 and stations 254-305, respectively. Samples were extracted within 10 days of the collection date. Salinity adjustments were required with 19 samples to attain 30±1 ppt. Hydrogen sulfide concentrations in 98 of the samples were below the detection limit of 0.01 mg/L. In samples 242 and 243 they were 12 and 8.5 mg/L and dissolved oxygen concentrations fell below 80% saturation. These samples were aerated by stirring to drop the sulfide levels to 0.5 and 0.05 mg/L, respectively. Porewater oxygen concentrations for the remaining samples ranged from 6.2 to 7.9 mg/L, equivalent to 80% and 102% saturation. Values for pH ranged from 6.8 to 7.8 in all samples. The environmental data indicated test conditions were acceptable. Fertilization success was 92.9% and 98.7% in the tests of 100% porewater from the Redfish Bay reference site in the two test runs, indicating the test animals were viable. EC50 concentrations determined for sodium dodecyl sulfate were similar to results from the previous phases of the survey (mean of 2.31 mg/L and range of 2.09 to 2.56 mg/L in the first test run and mean of 3.69 mg/L and range of 3.40 to 4.01 mg/L in the second run).

Total ammonia (TAN) concentrations in the porewater samples ranged from 0.16 to 17.8 mg/L and un-ionized ammonia (UAN) concentrations ranged from 1.4 to 398.6 ug/L. The LOEC for UAN for the fertilization test with *Arbacia punctulata* is 800 ug/L. No equivalent LOEC has been determined for *S. purpuratus*. Only one sample had an UAN concentration greater than 100 ug/L. The UAN concentration of 398.6 ug/L was recorded in sample 242 (Port of Olympia) and it was very toxic in all three porewater concentrations. The next highest concentration (85.2 ug/L) occurred in sample 213 (inner Port Gamble Bay). That sample was not toxic. The third highest concentration (81.2 ug/L) occurred in sample 270 (Gig Harbor). That sample also was not toxic.

Among the 100 samples, eleven were classified as significantly toxic (i.e., significantly different from reference at alpha<0.05) in tests of 100% porewater (Table 7). Percent fertilization success was less than 80% of reference in eight of the samples. Therefore, the incidence of significant toxicity in tests of 100% porewater was 11% and the incidence of highly toxic samples (i.e., percent fertilization <80% of reference) was 8% in 100% porewater. In comparison, the incidence of highly toxic samples in tests of 100% porewater was 15% in northern Puget Sound and 9% in central Puget Sound. Overall, the incidence of highly toxic responses in 100% porewater was 11% (32 of 300).

The toxicity of the samples was most severe in two samples (242 and 243 from Port of Olympia) in which fertilization success was 0.4% and 0.0%, respectively, in tests of 100% porewater. These two samples were also very toxic in tests of diluted porewater (0.0 and 0.4% in 50% porewater, and 0.2% and 3.8% fertilization in 25% porewater, respectively). The response was relatively severe also in samples 240 (inner Eld Inlet) and 294 (Commencement Bay waterways) in which fertilization success was 7.2% and 28.4%, respectively, in tests of 100% porewater.

In most cases, percent fertilization success increased as the pore waters were diluted from 100% to 50% and to 25%. However, there were a few samples in which this usual pattern was not observed. Statistically significant results were observed in tests of 50% and/or 25% porewater, but not in 100% porewater, in samples 228, 229, 230, 231, 248, and 250. These unusual results probably were a function of variability in the biological responses.

Microbial Bioluminescence (Microtox™)

The mean EC50 concentration for tests of the Redfish Bay control was 10.9 mg/L, similar to the value determined in the 1998 survey of central Puget Sound (10.6 mg/L). However, both of these results were an order of magnitude different from that of the 1997 survey of northern Puget Sound (102.9 mg/L), illustrating the unusual condition of the Redfish Bay control sample in 1997. Because of the anomalous control results in 1997, 80% and 90% LPL were calculated from a national data set for comparison with 1997 data. To maintain consistency in sample analysis and reporting, the 1998 and 1999 data are presented as significant deference from controls and less than 80% of controls, and in comparison to the 80% and 90% LPLs.

Microtox EC50 values were significantly different from the controls and less than 80% of controls in 73 samples (i.e., 73% incidence of highly toxic samples) (Table 8). In the 1997 and 1998 phases of the study, the percentages of highly toxic samples were 97% and 57%, respectively. Again, the data from 1997 reflect the unusual condition of the Redfish Bay control sample at that time.

EC50 values ranged from a mean of 0.31 mg/L (Port of Olympia) to 175.30 mg/L (East Passage). Expressed as percentages of controls, the responses ranged from 3% to 1608% of the Redfish Bay samples. With respect to the critical 80% and 90% lower prediction limit (LPL) values derived for this test during the 1997 survey of northern Puget Sound sediments (Long et al., 1999a), there were three samples with responses of less than 0.51 mg/L (80% LPL). The EC50 values for samples 243 (Port of Olympia), 293 (N.E. Commencement Bay), and 294 (Thea Foss Waterway) were 0.31, 0.43, and 0.32 mg/L and represented the most severe response in this test. None of the results were less than 0.06 mg/L (90% LPL) in any of the 300 samples tested from Puget Sound. There were 18 samples with responses >100% of the controls, whereas in 1998 there were 35 samples with comparable results.

Human Reporter Gene System (Cytochrome P450) Response - Organic Solvent Extract

The cytochrome P450 HRGS toxicity test responses among the 100 samples ranged from 1.5 (station 280, East Passage) to 1994.9 μgB[a]Peq/g (station 294, Thea Foss Waterway) (Table 8). Statistical significance of these data compared to the controls was not determined. However, there were 43 samples in which the response was <11.1 μg/g (the 80% Upper Prediction Limit, UPL) critical threshold derived for the 1997 northern Puget Sound study (Long et al., 1999a), 57 in which responses were > 11.1 μg/g, and 17 with responses greater than 37.1 μg/g (the 90% UPL critical threshold). In the 1997 survey of northern Puget Sound, there were 84, 16, and 4 samples in these categories. In the 1998 survey of central Puget Sound, there were 38, 62, and

27 samples in these categories. Thus, the data indicated that overall, induction was slightly higher in southern Puget Sound than in the central region and considerably lower in the northern region than in the other two regions.

HRGS induction responses were most severe in samples 294, 295, and 296 from Thea Foss Waterway near Tacoma. Enzyme induction in these samples was 1995, 529, and 356 ug/g, respectively. Other samples in which the response exceeded 100 μg/g were collected at stations 206 (Port Ludlow), 243 (Port of Olympia), 287, 293, 299, 303, and 304 (all in Commencement Bay or adjoining waterways). The samples with the lowest responses (<2.0 μg/g) were collected at stations 245 (Pickering Passage), 268 (Hale Passage), and 280 (East Passage).

As a corollary to and verification of the cytochrome P450 HRGS toxicity test results, Columbia Analytical Services performed further chemical testing on a select number of the southern Puget Sound samples (Jack Anderson, CAS, personal communication). Tier II testing of ten samples was conducted with responses recorded at 6 hours and 16 hours to identify the contribution of PAHs and dioxin/furan chemicals to the enzyme induction. Samples from stations 280, 281, 287, 290, 291, 294, 295, 303, 304, and 305 were selected for these assays because they provided a distinct response gradient from the Thea Foss Waterway seaward into East Passage of Puget Sound. In all samples, the response was much greater at 6 hours than at 16 hours, indicating the response was primarily driven by the presence of PAH chemicals and minimally attributable to the chlorinated chemicals.

In subsequent Tier III testing of samples 294, 303, and 304, the concentrations of total PAHs (sum of 27 chemicals) were determined to be 57, 6, and 2 μg/g dry wt. The sums of total PCB congeners in these samples were 674, 137, and 68 ng/g, respectively. Sums of total planar congeners were 43, 15, and 7 ng/g, respectively. The data from the Tier II and Tier III tests, collectively, confirmed that the samples from Thea Foss Waterway were highly contaminated relative to the others and had high concentrations of PAHs. The degree of contamination and enzyme induction observed in these samples decreased steadily in samples collected in outer Commencement Bay and East Passage.

Spatial Patterns and Gradients in Toxicity

Spatial patterns in toxicity are illustrated in three sets of figures, including maps for the amphipod and urchin test results (Figures 4-7), Microtox™ results (Figures 8-11), and cytochrome P450 HRGS test results (Figures 12-15). Amphipod and urchin test results are displayed as symbols keyed to the statistical significance of the responses. Stations are shown in which amphipod survival was not significantly different from CLIS controls ($p \geq 0.05$, i.e., non-toxic), or was significantly different from controls ($p < 0.05$, i.e., significantly toxic), or was significantly different from controls ($p < 0.05$) and less than 80% of control survival, (i.e., highly toxic). Also, stations are shown on the same figures in which urchin fertilization (100% pore water) was not significantly different from Redfish Bay controls ($p \geq 0.05$, i.e., non-toxic), or was significantly different from controls ($p < 0.05$) and less than 80% of controls (i.e., highly toxic) in 100% pore water only, or in 100% and 50% porewater concentrations, or in 100% and 50% and 25% porewater concentrations. Samples in which significant results were observed in all three porewater concentrations were considered the most toxic.

Microtox™ and cytochrome P450 HRGS data are shown as histograms for each station. Microtox™ results are expressed as the mean EC50 (mg/ml), therefore, as in the report for the 1997 and 1998 surveys, the height of the bar decreases with increasing toxicity. Dark bars indicate non-significant results. In the cytochrome P450 HRGS assays, data are expressed as benzo[a]pyrene equivalents (μg/g) of sediment. For these results, high values indicate the presence of toxic chemicals, i.e., the height of the bar increases with increasing toxicity.

Amphipod Survival and Sea Urchin Fertilization

None of the results of the amphipod survival tests were significant in the Hood Canal and vicinity (Figure 4). In the sea urchin tests, results were significant in tests of three samples at 100% porewater concentrations. Fertilization success was reduced in one sample from Port Gamble Bay (station 214) and in two samples from Dabob Bay (219 and 220). None of the results were significant at diluted porewater concentrations.

In the many inlets and channels of southern Puget Sound, most samples were similarly non-toxic in these two tests (Figure 5). One of the samples (station 245, Pickering Passage) was significantly, but not highly toxic in the amphipod survival tests, and only four were toxic in the sea urchin tests. Toxicity was recorded in one sample from Totten Inlet (station 235), one sample from Eld Inlet (station 240), and two samples from Port of Olympia (station 242, 243). The two samples from Port of Olympia were the most toxic in the urchin tests. Fertilization success in these two samples was 0% in 100% porewater, 0% to 0.4% in 50% porewater, and 0.2% to 3.8% in 25% porewater. The high degree of toxicity observed in Port of Olympia diminished rapidly seaward into Budd Inlet, where none of the samples were toxic.

In the Case Inlet/Carr Inlet/Nisqually Reach area, only one sample was toxic in the amphipod tests (station 254) and none were toxic in the urchin tests (Figure 6). Amphipod survival was 92% of controls in the sample from station 254. Although classified as "significantly toxic" (i.e., significantly different from survival in controls), mean survival was relatively high in this sample. Results were similar in the samples collected from Commencement Bay and vicinity (Figure 7). Toxic responses were recorded in one sample (station 294 at the head of Thea Foss Waterway) in both of the tests. The results of the urchin tests were significant in both 100% and 50% porewater concentrations.

Microbial Bioluminescence (Microtox™)

As indicated by the tall bars of the histogram (Figure 8-11), most of the samples from Hood Canal and vicinity were not toxic in this test; however, toxic responses were recorded in all six samples collected in Port Ludlow and Port Gamble Bay (Figure 8). Also, two samples each from both the seaward (stations 209, 211) and the landward (stations 224, 225) ends of the canal indicated toxic responses. None of the samples from the Quilcene Bay/Dabob Bay area were toxic in this test.

Samples from the inlets of southern Puget Sound were considerably different from those from Hood Canal – all except one (station 246) were significantly toxic (Figure 9). Diminished bioluminescence activity (indicated by low EC50 concentrations) was most apparent in the samples collected in inner Oakland Bay near the city of Shelton and in those from the Port of Olympia. EC50 concentrations recorded for the three samples from the Port of Olympia were among the lowest for all 100 samples tested. Responses were significant in samples from the other South Sound inlets, but not nearly as severe as in those from Oakland Bay and the Port of Olympia.

Toxic responses diminished in the strata sampled farther to the east (i.e., seaward). EC50 concentrations were somewhat higher and four of the samples were non-toxic in the Case Inlet/Carr Inlet/Nisqually Reach area (Figure 10).

Toxic responses were recorded in most samples from Commencement Bay and adjoining waterways (Figure 11). The most severe responses were apparent in samples from the industrialized waterways of Tacoma. The severity decreased incrementally seaward into the outer reaches of the bay and, again, into the East Passage of Puget Sound. Samples from stratum 30 (Thea Foss Waterway), stratum 31 (Middle Waterway), and stratum 33 (Hylebos Waterway) were among the most toxic in the study. Toxicity in these tests was also apparent in samples from inner Quartermaster Harbor and Gig Harbor, but not in samples from Colvos Passage and all except one sample from East Passage.

Human Reporter Gene System (Cytochrome P450)

As opposed to the Microtox™ tests, exposures to contaminated samples in these tests are indicated with increasing responses. Responses greater than 37.1 μg/g benzo[a]pyrene equivalents are considered elevated. Most samples from Hood Canal and vicinity did not cause elevated responses in this test. However, the sample from station 206 in Port Ludlow produced a response equivalent to 103 μg/g (Figure 12). The sample from station 214 collected in Port Gamble provided a response of 37 μg/g. Otherwise, the samples from this area indicated background conditions.

HRGS induction was elevated in one sample (station 227) from Oakland Bay and two samples (242, 243) from the Port of Olympia (Figure 13). In both cases, the degrees of induction declined rapidly in stations sampled seaward of these inner harbor areas. Stations that were sampled elsewhere in the South Sound inlets showed background responses in these tests. Similarly, relatively low induction levels (i.e., <37.1 μg/g) were observed in all samples from strata 16-21 (Figure 14).

In contrast, conditions in the waterways of Commencement Bay were considerably different than those elsewhere in the study area. HRGS responses were extremely high in the three samples from stratum 30 (Thea Foss Waterway), ranging from 356 μg/g to 1995 μg/g (Figure 15). These results rank among the highest degrees of response observed in NOAA studies nationwide and exceeded the levels of response in samples tested from Everett Harbor and the lower Duwamish River Waterways (Long, et al. 1999a, 2000). HRGS induction also was very high in the samples from strata 31 and 33, in all cases exceeding 37.1 μg/g. Response levels were also high at stations 287 off the mouth of Thea Foss Waterway and station 293 between Browns Point and the mouth of Hylebos Waterway. Although the degree of response in these assays generally diminished seaward into the East Passage, the sample from station 278 off Browns Point indicated elevated induction. In Gig Harbor, the HRGS response was elevated in station 271 and somewhat lower (31-33 μg/g) in the other two samples from that bay. Samples from Quartermaster Harbor and northern Colvos Passage indicated background conditions.

Summary

Several spatial patterns in toxicity were apparent in this survey area. First and foremost, toxic responses in the two tests of organic solvent extracts were most severe in some of the industrialized waterways of Commencement Bay at Tacoma. The HRGS responses in the three samples from Thea Foss Waterway were very high. They were accompanied by significant toxicity in the Microtox™ tests in all three samples and significant responses in both the amphipod and urchin tests in one of the samples. The degree of toxicity in Hylebos and Middle Waterways was lower, but, nonetheless, represented conditions considerably different from those reported elsewhere in the survey area. The degree of toxicity in the Commencement Bay waterways incrementally and gradually diminished seaward into the outer reaches of the bay and decreased again into East Passage.

Other industrialized harbors in which sediments induced toxic responses on smaller scales included the Port of Olympia, Oakland Bay at Shelton, Gig Harbor, Port Ludlow, and Port Gamble. In each case, the toxic responses diminished sharply with increasing distance from these harbors. Sediments in most of the South Sound inlets and passages were relatively homogeneous, i.e., not toxic in most of the tests. The patterns of toxicity in the southern Puget Sound, i.e., toxic conditions restricted mainly to industrialized harbors and improving quickly into more rural or undeveloped areas or into the main basin, also were observed in the studies of northern and central Puget Sound.

Spatial Extent of Toxicity

The spatial extent of toxicity was estimated for each of the four tests performed in central Puget Sound with the same methods used in the 1997 and 1998 surveys. The critical values used in 1997 and 1998 also were applied to the 1999 data. The 33 strata were estimated to cover a total of about 858 km^2 in the southern Puget Sound survey area (Table 9).

Control-adjusted amphipod survival was greater than 80% in all samples, therefore, the spatial extent of toxicity was 0.0% (Table 9). Urchin fertilization was less than 80% in samples that represented 6% of the area with tests of 100% porewater concentration, 0.5% with tests of 50% porewater, and 0.3% with tests of 25% porewater.

The spatial extent of toxicity using EC50's <80% of controls as the critical value, was 61% in the Microtox tests. However, relative to the statistically-determined 80% and 90% lower prediction limits of the Microtox™ database, the spatial extent of toxicity was estimated as 0.2% and 0.0%, respectively. In the cytochrome P450 HRGS assays, samples in which the responses exceeded 11.1 μg/g and 37.1 μg/g (the 80% and 90% upper prediction limits of the existing database) represented about 329 km^2 and 43 km^2, respectively. These areas were equivalent to 38% and 5%, respectively, of the total survey area.

Concordance among Toxicity Tests

Non-parametric Spearman-rank correlations were determined for combinations of the four different toxicity tests to determine the degree to which the results co-varied and, therefore, showed the same patterns. It is critical with these correlation analyses to identify whether the coefficients are positive or negative. Amphipod survival, urchin fertilization success and microbial bioluminescence EC50's improve as sediment quality improves. However, cytochrome P450 HRGS responses increase as sediment quality deteriorates. Therefore, in the former three tests, positive correlation coefficients suggest the tests co-varied with each other. In contrast, co-variance of the other tests with results of the cytochrome P450 HRGS assays would be indicated with negative signs.

The results showed a very strong negative correlation between microbial bioluminescence and cytochrome P450 HRGS induction (Table 10). That is, HRGS induction increased as the Microtox™ EC50's decreased, meaning that the results of these two tests were highly concordant. These two tests were performed on subsamples of the same organic solvent extracts. Often, they indicated that samples from the industrialized harbors such as the Commencement Bay waterways and Port of Olympia were most contaminated and that most samples from more rural inlets and passages of southern Puget Sound were indicative of background or reference conditions. Similarly, urchin fertilization was negatively correlated with HRGS induction, but the correlation was not as strong as it was between Microtox™ results and HRGS induction.

Chemical Analyses

Results of the sediment chemistry analyses conducted for this survey are presented in the following sections. Due to the large volume of data generated, brief summaries of the results are included below, while either raw or summary data tables are included in the Appendices. A record of all field notes and observations made for each sediment sample collected is summarized in Appendix F. As stated earlier, all raw data can be obtained from the Ecology Sediment Monitoring Team's web site. The web site address is located on the inside cover of this report.

Grain Size

The grain size data are reported in Appendix G, Table 1, and frequency distributions of the four particle size classes, % gravel, % sand, % silt, and % clay, are depicted for all stations in Appendix G, Figure 1. From these data, sediment from the 100 stations were characterized into four groups (sand, silty sand, mixed sediments, and silt-clay) based on their relative proportion of % sand to % fines (silt + clay) (Table 11). Among the 100 samples from southern Puget Sound, 24 were comprised primarily of sand, 12 of silty sand, 40 had mixed sediments, and 24 were comprised primarily of fine-grained (silt-clay) particles.

Total Organic Carbon (TOC), Temperature, and Salinity

Total organic carbon (TOC) and temperature measurements taken from the sediment samples, and salinity measurements collected from water in the grab, are displayed in Appendix G, Table 2. Values for TOC ranged between 0.06 and 7.9%, with a mean of 1.8% ±1.3%. Four of the 100 stations had TOC values lower than 0.2% which should be considered when comparing TOC normalized data from these stations to Washington Sate sediment criteria (Michelsen, 1992). Temperature ranged between 11 and 15 °C, with a mean of 11.7 ±1.0. Salinity values ranged between 23-32 ppt, with a mean of 29.1% ±2.1%.

Metals and Organics

Appendix G, Table 3 contains summary data for the detected concentrations of metals and organic chemicals, including mean, median, minimum, maximum, and range values, as well as the total number of values, the number of undetected values, and the number of missing values. Chemicals which, at some or all stations, were undetected at the quantitation limits reported by the laboratory included 5 of 23 metals (strong acid digestion), 7 of 22 metals (hydrofluoric acid digestion method), 1 of 2 elements, 5 of 5 organotins, 24 of 24 organic chemicals quantified through BNA analyses, 27 of 46 low and high molecular weight polynuclear aromatic hydrocarbons, and all 58 chlorinated pesticides and polychlorinated biphenyl (PCB) chemicals.

Spatial Patterns in Chemical Contamination

The spatial (geographic) patterns in chemical contamination were determined by indicating the locations of sampling stations on maps in which numerical sediment quality guidelines and criteria (ERM, SQS, and CSL values) were exceeded (Figures 16-19). The number and list of chemical chemicals that exceeded these guideline and criteria values at each station, along with the mean ERM quotient for each station, are listed in Table12.

Most samples had chemical concentrations that were low relative to the ERM, SQS, and CSL values (Table 12). There were 80 samples in which all chemical concentrations were below all of these guidelines and criteria. One or more chemical concentrations exceeded their respective ERL values in 82 samples, indicating at least a slight degree of contamination in these samples. One or more ERM values were exceeded in 9 samples. One or more SQS values were exceeded in 17 samples and these concentrations exceeded the respective CSL values in 10 samples. There were 6 samples in which both the ERM values and the SQS (and in 3 cases, the CSL) values were exceeded. As indicated by the high mean ERM quotients and the numbers of guidelines and criteria exceeded, several stations (294-296, 299, 303-305) from the industrialized waterways of Commencement Bay had the highest degrees of chemical contamination encountered in the survey.

In the Hood Canal area (Figure 16, Table 12), there were three samples (one from Port Ludlow and two from Port Gamble Bay) in which one or more sediment quality values were exceeded. In station 207 (Port Ludlow), the concentration of naphthalene exceeded the SQS value. In Port Gamble Bay, silver was elevated in concentration in station 212, while several low molecular weight PAHs (LPAH) and the sum of LPAH were elevated in concentration relative to their respective ERM values in station 214.

Relative to Hood Canal, the SQS and CSL values were exceeded more frequently in the samples from southern Puget Sound inlets (Figure 17, Table 12). The concentration of mercury exceeded the ERM, SQS and CSL values in the sample from station 235 (Totten Inlet). Concentrations of benzoic acid, benzyl alcohol, and/or phenol exceeded SQS and CSL levels in the other samples from this region of the study area, including Budd Inlet and the Port of Olympia, Pickering Passage/Squaxin Island, and Henderson Inlet. Bis(2-ethylhexyl) phthalate also exceeded the SQS value at station 243 in the Port of Olympia. In addition, benzoic acid also was elevated in concentration in stations 260 (East Anderson Island) and 266 (Hale Passage) (Figure 18, Table

12). Otherwise, most samples from the inlets of southern Puget Sound did not have elevated concentrations of any of the substances for which there are state criteria or NOAA guidelines.

None of the samples collected in Colvos Passage, East Passage, Quartermaster Harbor, Gig Harbor, or outer Commencement had high chemical concentrations (Figure 19). However, eight samples collected in the Tacoma waterways or off the Tacoma waterfront had chemical contaminant values exceeding ERM, SQS, and/or CSL levels. The concentrations of LPAHs were relatively high in stations 287 (Commencement Bay shoreline), and 294-296 (Thea Foss Waterway). The concentrations of many LPAHs and HPAHs were very high in the sample from station 294. This sample also had elevated concentrations of PCBs, 2,4-dimethylphenol, lead, and mercury and a very high mean ERM quotient.

The sample from station 299 (Middle Waterway) was contaminated with a mixture of PAHs and trace metals, but the samples collected nearby at stations 297 and 298 had considerably lower chemical concentrations (Figure 19, Table 12). The chemical mixture in station 299 was similar to that in the contaminated samples from Thea Foss Waterway. In contrast, the samples from Hylebos Waterway were primarily contaminated with PCBs and hexachlorobenzene (HCB), but not with the PAHs. Also, phenol was elevated in concentration at station 304.

Summary

In summary, 20 of the 100 samples collected had one or more chemical concentrations that exceeded applicable guidelines or criteria. Among these samples chemical contamination was highest in eight samples collected in or near the industrialized waterways of Commencement Bay. Samples from the Thea Foss and Middle Waterways were primarily contaminated with a mixture of PAHs and trace metals, whereas those from Hylebos Waterway were contaminated with chlorinated organic hydrocarbons. The remaining 12 samples with elevated chemical concentrations primarily had high levels of other chemicals, including bis(2-ethylhexyl) phthalate, benzoic acid, benzyl alcohol, and phenol. There was a distinct spatial pattern in contamination in Commencement Bay (i.e., high concentrations in the waterways diminished rapidly into the outer reaches of the bay). However, there were no other equally clear gradients elsewhere in the study area.

Spatial Extent of Chemical Contamination

To estimate the spatial extent of chemical contamination, the numbers of samples were tallied in which ERM, SQS, and/or CSL values were exceeded. Then, the percentages were calculated of the survey area that these samples represented for all substances for which state standards and /or NOAA guidelines were available (Table 13). For some chemicals (e.g., phenols, phthalate esters), the data were qualified as "undetected" at practical quantitation limits that exceeded the chemical guideline and/or criteria values. In these cases, the spatial extent of chemical contamination was recalculated after omitting the data that were so qualified (shown as ">QL only" on Table 13). Calculations were performed both ways (i.e., by including, then omitting data at or below the quantitation limit) to be consistent with methods used in the 1997 and 1998 reports and to quantify the significance of the qualified data.

Among the trace metals that were measured, the concentrations of mercury and nickel were elevated most frequently (Table 13). With the exception of nickel, however, the samples with elevated concentrations of one or more trace metals represented less than 1% of the total survey area. Long et al. (1995), suggested that there was a limited degree of reliability in the ERM for nickel. For all trace metals (excluding nickel), there were a total of 4 (ERM), 3 (SQS), and 3 (CSL) samples that exceeded guidelines or criteria levels, encompassing a total of 0.84, 0.68, and 0.68%, respectively, of the total study area.

Concentrations of individual LPAHs or the sum of LPAHs were elevated relative to the guidelines or standards in 1 to 6 samples located in Commencement Bay, Thea Foss and Middle Waterways, Port Ludlow, and Port Gamble Bay. These samples represented from <0.01 to 0.30% of the total study area. High molecular weight PAHs were present in concentrations above standards and guidelines only in two stations from the Thea Foss Waterway and one from Middle Waterway in Tacoma, representing from <0.01 to 0.03% of the total study area.

Concentrations of phenol exceeded SQS and CSL values in samples from the Port of Olympia, Henderson Inlet, and Hylebos Waterway (0.25 and 0.22% of the total study area, respectively), while concentrations of 2,4-dimethylphenol exceeded these values in the Thea Foss Waterway (0.01% of the total study area). The samples in which the SQS values or CSL values were exceeded for one or more phenols (>QL only) represented about 0.26% and 0.24% of the survey area, respectively. Similarly, the one sample (Thea Foss Waterway) with phthalate ester concentrations greater than the SQS values (>QL only) represented a small percentage of the total survey area (0.01%). The concentrations of PCB chemicals were elevated in a few samples (>QL only), all from the Tacoma waterways. Benzoic acid concentrations (>QL only) exceeded both the SQS and CSL values in 5 samples, representing 3.21% of the area. Benzyl alcohol concentrations (>QL only) exceeded SQS and CSL values in 3.09 and 1.86% of the study area. Three samples had concentrations of hexachlorobenzene greater than the SQS, representing about 0.08% of the study area.

The overall spatial extent of chemical contamination as gauged by the total number of chemical values exceeding one or more of the ERM, SQS, and CSL values, is summarized at the end of Table 13. There were 9 samples in which one or more ERM values were exceeded by any amount (excluding nickel for which the ERM is least reliable). These 9 samples represented about 1% of the total survey area. In contrast, there were 17 and 10 samples in which one or more SQS or CSL values, respectively, were exceeded (>QL only). Those samples represented about 7% and 5%, respectively, of the survey area.

Summary

The spatial extent of chemical contamination, expressed as the percent of the total study area in which a chemical concentration exceeded one or more of the state criteria or NOAA guidelines or criteria, was determined for the 54 chemicals for which these values exist. In general, the majority of chemicals for which analyses were conducted on the 100 sediment samples from southern Puget Sound were measured at levels below state criteria and NOAA guidelines. The samples in which chemical concentrations exceeded the criteria or guidelines tended to be isolated to a very small percentage (generally <1%) of the study area. For all trace metals (excluding nickel), there were a total of 4 (ERM), 3 (SQS), and 3 (CSL) samples in which guidelines or criteria levels were exceeded, encompassing a total of 0.84, 0.68, and 0.68%, respectively, of the total study area. Significant metals contamination occurred in Port Gamble Bay, Totten Inlet, and in both the Thea Foss and Middle Waterways of Commencement Bay, and mercury was the most commonly found contaminant. There were totals of 6, 4, and 1 samples with PAHs exceeding ERM, SQS, and CSL values, respectively, encompassing a total of 0.30, 0.23, and <0.01% of the total study area. Contaminants were again located in Port Gamble Bay and Commencement Bay, including both the Thea Foss and Middle Waterways. PCB chemicals exceeded guidelines and criteria in 2 (ERM) and 3 (SQS) stations in the Thea Foss and Hylebos Waterways, representing 0.04 and 0.07% of the study area. Other organic chemicals, including benzoic acid and benzyl alcohol exceeded SQS and CSL values in 5 or fewer samples, roughly 3% or less of the study area, including stations in Budd Inlet, Port of Olympia, Henderson Inlet, E. Anderson Island, and Hale and Pickering Passages. Hexachlorobenzene values exceeded the SQS value at all three stations in the Hylebos Waterway (0.08% of the study area).

Relationships between Measures of Toxicity and Chemical Concentrations

The associations between the results of the toxicity tests and the concentrations of potentially toxic substances in the samples were determined in several steps, beginning with simple, non-parametric, Spearman-rank correlation analyses. This step provided a quantitative method to identify which chemicals or chemical groups, if any, showed the strongest statistical relationships with the different measures of toxicity. In the second step, some of the most statistically significant correlations were further examined in scatterplots. Finally, where warranted by the data, the applicable sediment quality guidelines or state standards were shown on the scatterplots to identify which chemicals were elevated in concentration in the most toxic samples.

Toxicity vs. Classes of Chemical Chemicals

Spearman-rank correlation coefficients (rho) and probability (p) values for the four toxicity tests versus the concentrations of four different groups of chemicals, normalized to the respective ERM, SQS, and CSL values, are listed in Table 14. As expected because of the narrow range in response, results of the amphipod survival tests were not significantly correlated with any of the classes of chemicals in the samples. Sea urchin fertilization was weakly correlated (p values ≤ 0.05 or ≤ 0.01) mainly with classes of PAHs. The strongest statistical correlations were between results of both the Microtox™ and HRGS tests and the concentrations of most chemical classes. In particular, HRGS induction was correlated with concentrations of total (13) PAHs normalized to the ERM values (rho = 0.816, $p \leq 0.0001$) and mean ERM quotients for 25 individual substances (rho = 0.805, $p \leq 0.0001$). Both of these tests are known to be responsive to doses of PAHs and results such as these have been reported in previous studies in Puget Sound and elsewhere in NOAA's surveys of other U. S. estuaries. HRGS induction was also highly correlated ($p \leq 0.0001$) with chemical groups normalized to the respective SQS and CSL values. However, the correlation coefficients were somewhat lower than those determined with chemical concentrations normalized to the ERM values.

Toxicity vs. Individual Chemicals

Correlations between measures of toxicity and concentrations of individual trace metals determined with both partial and total digestion metals are summarized in Tables 15 and 16. No significant results were seen with amphipod survival or urchin fertilization tests. Results of both of the tests run with the organic solvent extracts, however, showed highly significant correlations with the concentrations of several trace metals. Because the microbial bioluminescence and cytochrome P450 HRGS tests were performed with organic solvent extracts, trace metals were not expected to contribute significantly to the biological responses in these tests. The correlations between results of these two tests and concentrations of trace metals that appear to be highly significant may reflect the co-variance in concentrations of metals and the organic toxicants that were eluted with the solvents and were more likely to have caused the responses.

The cytochrome P450 HRGS response was highly correlated with the concentrations of all low molecular weight PAHs (Table 17), high molecular weight PAHs (Table 18), and summed concentrations of these chemical classes. Results of the Microtox™ tests also were highly correlated with PAH concentrations, but to a somewhat lesser degree than in the HRGS tests. The correlations with the HRGS response were higher for the high molecular weight substances than for the low molecular weight chemicals. In addition to the PAHs, the concentrations of carbazole and dibenzofuran were highly correlated with the Microtox™ and HRGS assay results, the latter more so than the former (Table 19). The HRGS assay is known to respond to some PCB congeners that share some toxicological properties with dioxins and furans, but it is largely unresponsive to most congeners. In these samples, the HRGS assay results were highly correlated ($p<0.0001$) with the concentrations of total PCB congeners and total chlorinated organic hydrocarbons (HCHs) (Table 20). The correlations were somewhat weaker ($p<0.001$) with concentrations of total PCB Aroclors, Aroclor 1254, and congener 101.

Scatter Plots

The relationships between HRGS induction vs. the mean ERM quotients for 25 chemical substances and the concentrations of 13 PAHs are illustrated in Figures 20 and 21. In both cases, the correlations were highly significant ($p\leq0.0001$). A cluster of stations with very low chemical concentrations appears in the lower left corner of both diagrams. As chemical concentrations incrementally increased, however, induction gradually increased. Two samples from Thea Foss Waterway with intermediate chemical concentrations induced the HRGS response to levels of 355 and 529 ug/g. The data point in the upper right corner of the diagrams represents the sample from Thea Foss station 294 in which the HRGS response was 1995 ug/g, the highest observed in all 300 Puget Sound samples. Samples that had total PAH concentrations less than the ERL value showed the lowest responses. HRGS responses generally were intermediate as PAH concentrations exceeded the ERL. The response was highest in the sample with the PAH concentration greater than the ERM value. Therefore, these scatterplots tend to verify dose-response relationships initially indicated with the correlation coefficients.

The results of the Microtox™ tests vs. the mean ERM quotients for 25 substances and the sum of 13 PAH concentrations also were highly significant ($p\leq0.0001$), but the coefficients were somewhat lower than observed with the HRGS tests (Table 14, Figures 22, 23). Expressed as percentages of the control responses, the Microtox™ results showed a range in response in the least contaminated samples. As mean ERM quotients approached values of about 0.25 and total PAH concentrations began to exceed the ERL value, the variability in responses among samples decreased and EC50 values decreased as chemical concentrations increased.

The relationship between the HRGS assay responses and PAH concentrations is further illustrated in three scatterplots (Figures 24, 25, 26). The correlations were highly significant ($p \leq 0.0001$), and the least contaminated samples had the lowest HRGS responses. However, the patterns in response were not as clear as with total PAH concentrations and mean ERM quotients, and were probably driven, in part, by the very high HRGS response value from Thea Foss station 294. These correlations would be expected, given that the correlations with the mean sediment guideline and/or criteria quotients for PAHs were significant and given that these substances rarely occur in nature alone, but, rather, as complex mixtures.

Summary

The strong statistical correlations between the HRGS response and the concentrations of PAHs and other organic substances were similar to what was observed in the 1997 and 1998 phases of this survey. Therefore, there appears to be a consistent response with this test among the three study areas, suggesting that complex mixtures of organic substances were driving the response. Whereas the urchin fertilization tests showed correlations with chemical concentrations in northern and central Puget Sound, they failed to indicate such patterns in southern Puget Sound. In contrast, the Microtox™ tests indicated strong correlations with mixtures of chemical concentrations in northern and southern Puget Sound, but much weaker correlations in the central area. Amphipod survival tests largely failed to respond to any of the samples, and, therefore, did not indicate significant chemical correlations in any of the three areas.

Benthic Community Analyses

Community Composition and Benthic Indices

A total of 604 benthic infauna taxa were identified in the 100 samples collected in southern Puget Sound (Appendix H). Of the 604 taxa identified, 427 (71%) were identified to the species level. Among the 427 species identified, 216 (51%) were polychaete species, 87 (20%) were arthropods, 77 (18%) were molluscs, and 47 (11%) were echinoderms and miscellaneous taxa (i.e., Cnidaria, Platyhelminthes, Nemertina, Sipuncula, Phoronidae, Enteropneusta, and Ascidiacea) and echinoderms. Several of the species encountered in this survey may be new to science.

As described in the Methods section, five benthic infaunal indices were calculated to aid in the examination of the community structure at each station. These indices included total abundance, major taxa abundance (calculated for Annelida, Arthropoda, Mollusca, Echinodermata, and miscellaneous taxa), taxa richness, Pielou's evenness (J'), and Swartz's Dominance Index (SDI), and were calculated based on the abundance data collected for the 604 taxa found (Tables 21 and 22). Total abundance is displayed in both tables to facilitate comparisons among indices. All data were based on analysis of a single sample collected at each station.

Total Abundance

Total abundance (number of individuals per $0.1 m^2$) of benthic invertebrates at each station ranged from 3476 at station 213 (Port Gamble Bay) to 0 at stations 242 and 243 (Port of Olympia) (Table 21 and 22), with a mean of 645 $\pm$ 623 standard deviation. Sediment samples at eleven stations located in Port of Olympia (stations 242, 243), Dabob Bay (stations 219, 220), Eld Inlet (station 240), central Hood Canal (stations 221, 223), Oakland Bay (stations 230-232), and Carr Inlet (station 264) had 100 or fewer individual organisms. Sediment samples at 17 stations had greater than 1000 individual organisms. These stations were located in Port Gamble (stations 212, 213), Port Ludlow (208), Pickering Passage/Squaxin Island (station 247), East Passage (station 278), Gig Harbor (station 269, 270), NE and SE Commencement Bay (stations 287, 288, 290, 293), and Thea Foss (295, 296), Middle (297, 299), and Blair (301, 302) Waterways. The polychaetes *Aphelochaeta* sp. N1 and *Aphelochaeta* sp. were the dominant organisms in 10 of these 17 samples, while the mollusc *Axinopsida serricata* was dominant in three, and the polychaete *Cossura pygodactylata* was dominant at two of these stations with high total abundance.

Major Taxa Abundance

Total abundance and percent total abundance of five major taxonomic groups (Annelida, Arthropoda, Mollusca, Echinodermata, and miscellaneous taxa) are shown in Table 21. Results also are compared among stations in stacked histograms (Appendix I).

The total abundance of annelids ranged from 3202 in Port Gamble Bay (station 213) to 0 in Port of Olympia stations 242 and 243, where no organisms were present, with a mean of 398 $\pm$ 528 standard deviation. Annelid abundance calculated as the percentage of total abundance ranged from 93% (station 225, south Hood Canal) to 0% (Port of Olympia stations 242 and 243). Annelids were the dominant taxa in many samples, representing over 33% of the total abundance in 78 of the 100 samples, over 50% in 60 samples, and 80% or more of the total abundance in 22 samples. Annelid abundance was equal to or greater than 90% of total abundance in samples collected in Port Gamble Bay (station 213), southern Hood Canal (station 225), inner Eld Inlet (station 240), Port of Olympia (station 244), Gig Harbor (station 270), southeastern Commencement Bay (station 288, 290), Middle Waterway (station 299), and Hylebos Waterway (station 305). That is, annelids often were dominant in some of the urbanized harbors in which elevated chemical concentrations and significant toxicity were observed.

In sharp contrast to the annelids, the arthropods were rarely dominant. Total abundance of arthropods ranged from 731 (station 208, Port Ludlow) to 0 (station 225, Hood Canal; stations 242 and 243, Port of Olympia; station 264, Carr Inlet), with a mean of 85 $\pm$ 129 standard deviation. Percent total abundance of arthropods ranged from 75% in Henderson Inlet (station 250) to 0 % (station 225, Hood Canal; stations 242 and 243, Port of Olympia). Arthropods represented over 33% of the total abundance in 15 of the 100 samples, and over 50% of the total organisms in only six samples, including northern Hood Canal (station 209), Oakland Bay (station 230), two from Eld Inlet (stations 238, 239), and two from Henderson Inlet (stations 249, 250).

The total abundance and relative abundance of molluscs as percentages of the totals were slightly higher than that for the arthropods. Total abundance of molluscs ranged from 898 (station 287, southeast Commencement Bay shoreline) to 0 (stations 242 and 243, Port of Olympia), with a mean of 127 $\pm$ 156 standard deviation. Percent total abundance of molluscs ranged from 70% in East Passage (station 279) to 0 % (stations 242 and 243, Port of Olympia). Molluscs represented over 33% of the total abundance in 23 of the 100 samples, and over 50% of the total benthos in only six samples, including Carr Inlet (station 264), East Passage (station 279); outer, northeast, and southeast Commencement Bay (stations 283, 286, and 291); and Thea Foss Waterway (station 294).

The echinoderms were less abundant than the three other phyla in almost all samples. Total abundance of echinoderms ranged from 445 (station 237, Budd Inlet) to 0 in 31 stations. The 31 stations in which there were no echinoderms observed in the samples, included those in Port Ludlow (3), Dabob Bay (1), Hood Canal (4), Port of Shelton (2), Oakland Bay (1), Totten and Eld Inlets (2), Port of Olympia (2), Case and Carr Inlets (3), Hale Passage (1), Gig Harbor (2), Colvos Passage (1), Quartermaster Harbor (1), southeast Commencement Bay (3), and Thea Foss, Blair, and Hylebos Waterways (5)) (mean 22 $\pm$ 67 standard deviation, mode = 0). Percent total abundance values ranged from <1.0% in 63 samples, >1 to <10% in 28 samples, >10 to <23% in 6 samples, and between 36 and 55% in 3 samples in Budd Inlet (stations 237 and 241) and Drayton Passage (station 259).

Total abundance of miscellaneous taxa (i.e., Cnidaria, Platyhelminthes, Nemertina, Sipuncula, Phoronidae, Enteropneusta, and Ascidiacea) was also low in most samples, ranging from 354 (station 247, Pickering Passage/Squaxin Island) to 0 (10 stations including station 208, Port Ludlow; 214, Port Gamble; 219, Dabob Bay; 227, Port of Shelton; 240, Eld Inlet; 242 and 243, Port of Olympia; and 264, Carr Inlet; 269, Gig Harbor; and 301, Blair Waterway) (mean of 13 $\pm$ 37 standard deviation). Percent total abundance values ranged from <1.0% in 39 samples, >1 to <10% in 56 samples, >10 to <15% in 4 samples, and 33% in one sample. These miscellaneous phyla were rarely the dominant species in a sample (with the exception of the sipunculid, *Edwardsia sipunculoides,* at stations 245 and 247 in Pickering Passage/Squaxin Island), and, as with the echinoderms, generally were relatively minor contributors to total taxa numbers and total abundance.

Taxa Richness

Taxa richness, the total numbers of recognizable taxa in each sample, ranged from 0 in two samples from Port of Olympia (stations 242, 243) to 117 taxa in a sample from Middle Waterway (station 297)(Table 22), with a mean of 54 $\pm$ 26 standard deviations. There were 11 samples in which 90 or more taxa were found, indicating a very high diversity in the macrofauna. These samples were located primarily in passages, and large outer embayments and harbors, and included station 211, northern Hood Canal; stations 245-247, Pickering Passage/Squaxin Island; station 262, East Anderson Island/No. Cormorant Passage; station 272, Colvos Passage; station 275, Quartermaster Harbor; station 278, East Passage; stations 285 and 287, southeast Commencement Bay shoreline; and station 297, Middle Waterway. In contrast, there were eight samples in which 20 or fewer taxa were found. Most of the samples with low taxa counts were collected in various inlets and small embayments of the southern sound, including the Port of Olympia (stations 242-244), Eld and Totten Inlets (stations 240 and 234), Dabob Bay (stations 219-220), and southern Hood Canal (station 225).

Evenness

Pielou's index of evenness ranged from 0 in the two samples (stations 242 and 243) from the Port of Olympia, to 0.90 or more in two samples from Dabob Bay (stations 219, 220) and one sample from central Hood Canal (station 223)(Table 22) (mean of 0.67 $\pm$ 0.72 standard deviation). There were 17 samples in which the index was <0.50, the majority collected from terminal inlets in the southernmost part of Puget Sound. The samples were collected from Port Gamble and Port Ludlow (stations 206, 213), East Passage (station 279), Oakland Bay (station 230); Eld, Budd, and Henderson Inlets (stations 236-238, 250), the Port of Olympia (stations 242-243), Gig Harbor (stations 270), northeast and southeast Commencement Bay (stations 288, 290, 293), and the Thea Foss and Hylebos Waterways (stations 295, 305). Eighty-three samples had an evenness index greater than 0.50, while there were 25 samples in which the index was 0.8 or greater, indicative of a relatively even distribution of organisms among the various taxa. These 25 samples were collected from both smaller bays and inlets and larger passages and more open bodies of water including Quilcene and Dabob Bays (stations 215, 219-220), central Hood Canal (stations 221, 223), Oakland Bay (stations 231-232), Totten and Eld Inlets (stations 233, 235, 240), Pickering Passage/Squaxin Island (stations 245-247), Case and Carr Inlets (stations 253, 263); Drayton, Hale, East and Colvos Passages (258, 266, 268, 272-273, 280), East Anderson Island /Cormorant Passage (station 260-261), Quartermaster Harbor (stations 275-277), and southeast Commencement Bay (station 285).

Swartz's Dominance Index (SDI)

Values were calculated for this index to determine the number of taxa whose combined abundance accounts for 75 percent of the total abundance in each sample. The SDI values ranged from 0 in the two azoic samples from Port of Olympia (stations 242 and 243) to 31 in the sample from station 272 in northern Colvos Passage (Table 22) (mean 10 $\pm$ 7 standard deviation). Thirty-one samples had SDI values of 5 or less. The majority of these stations with low SDI values were located in urban or rural embayments and terminal inlets. These samples were collected from both East and Colvos Passages (stations 274, 279); Port Gamble, Port Ludlow, and southern Hood Canal (station 206, 212-213, 225-226); several south sound inlets and embayments (Port of Olympia, stations 242-244; Budd Inlet, stations 236-237, 241; Eld, Totten, and Henderson Inlets, stations 234, 238-240, 249-250; Oakland Bay, station 230; Gig Harbor, station 269-270); and from Commencement Bay (stations 290-291, 293) and the Thea Foss, Blair, and Hylebos waterways (stations 295, 300-303, 305). Thirty-two samples had SDI values between 6 and 10, while 16 samples had SDI values from 11-15. Twenty-one samples had SDI values ranging between 16 and 31. In contrast with the embayment/inlet samples with low SDI values (0-5), these 21 samples with the highest SDI values were located primarily in Puget Sound's passages, larger inlets, and outer embayments. These samples were located in north Hood Canal (stations 210-211), Quilcene Bay (station 216), Pickering Passage/Squaxin Island (station 245-247), Nisqually Reach (254), Drayton Passage (station 258), East Anderson Island/North Cormorant Passage (station 260-262), Carr Inlet (station 263), Hale Passage (266-268), Colvos Passage (stations 272-273), Quartermaster Harbor (station 275), East Passage (station 280), and outer and southeast Commencement Bay (stations 284-285).

Summary

As with the previous infaunal assemblage studies conducted in north and central Puget Sound (Long, et al. 1999a, 2000), benthic infaunal assemblages in south Puget Sound indicated a wide variety of characteristics in different locations and habitat types throughout the study area. Infaunal assemblages examined typically had relatively high abundance, taxa richness, evenness, and dominance values. Polychaetes were typically the most abundant taxa group (up to 93% of the infaunal composition), followed by arthropods (up to 75%), mollusks (up to 70%), echinoderms (up to 55%), and miscellaneous taxa (up to 33%). Total abundance was greatest at station 213 (Port Gamble Bay), while two samples collected in the Port of Olympia (stations 242 and 243) near a superfund cleanup site had no living organisms in them. In general, many of the small embayments and inlets throughout the study area had infaunal assemblages with relatively low total abundance, taxa richness, evenness, and dominance values. In some of the small urban/industrial embayments however, cases were found where total abundance values were very high, typically due to high abundance of one organism such as the polychaetes *Aphelochaeta* sp. N1, *Aphelochaeta* sp., or *Cossura pygodactylata*; the mollusk *Axinopsida serricata*; the arthropod *Aoroides spinosus*; and the echinoderm *Amphiodia urtica/periercta* complex. The majority of the samples collected from passages, outer embayments, and larger bodies of water tended to have infaunal assemblages with high total abundance, taxa richness, evenness, and dominance values.

Relationships between Benthic Infaunal Indices and Sediment Characteristics, Toxicity, and Chemical Concentrations

The statistical relationships between indices of benthic community structure and selected sediment characteristics were calculated using Spearman rank correlations. These correlations were used to determine if any of the measures of benthic community structure co-varied with any of the sediment characteristics quantified in this study. Measures of naturally occurring sediment variables such as grain size and total organic carbon (Table 23), toxicity (Table 24), and concentrations of chemical contaminants (Table 25-31) were included in the correlations with benthic infaunal indices.

Benthic Infauna Indices vs. Grain Size and Total Organic Carbon

Typically, concentrations of trace metals tend to increase with increased percent fines, and high concentrations of organic chemicals are often related to higher total organic carbon (TOC) concentrations in sediments. Since higher concentrations of toxic chemicals such as trace metals and organic chemicals are expected to be related to decreased benthic community abundance and variability, higher concentrations of fines and organic carbon are also expected to be related to decreased abundance and diversity. The correlations indicated that both taxa richness and the SDI values decreased as percent fine-grained materials increased (Table 23). However, these correlations were relatively weak ($p \leq 0.05$ or ≤ 0.01). The concentrations of fine-grained particles were not correlated with the other benthic indices. On the other hand, many of the calculated benthic indices were significantly correlated with the concentrations of TOC in the sediments. Taxa richness, SDI, and annelid abundance appeared to decrease significantly with increasing TOC concentrations. Several of the other indices also showed weak correlations with TOC content.

Benthic Infauna Indices vs. Toxicity

Most indices of benthic abundance and diversity would be expected to decrease with increasing toxicity, i.e., decreasing amphipod survival, decreasing urchin fertilization, decreasing Microtox™ EC50's, and increasing cytochrome P450 HRGS induction. Because there was no significant mortality in the amphipod tests, correlations between survival and benthic indices were not significant (Table 24). The abundance of arthropods and miscellaneous taxa were weakly correlated with urchin fertilization, indicating a slight pattern of declining abundance as fertilization success decreased. Results of the Microtox™ tests and HRGS assays, on the other hand, showed strong correlations with indices of evenness and dominance that were highly significant ($p \leq 0.0001$). As Microtox™ bioluminescence EC50 values decreased (indicating increasing toxicity), the evenness index and the numbers of dominant species also decreased. As HRGS induction increased (indicative of exposure of toxicants), the indices of evenness and dominance decreased. The abundance of miscellaneous taxa also decreased as HRGS induction increased ($p \leq 0.001$).

Benthic Infauna Indices vs. Classes of Chemical Chemicals

Spearman-rank correlations were calculated for benthic indices vs. concentrations of chemical groups normalized to their respective sediment guidelines or criteria (Table 25) to determine if they corresponded with each other. The data indicated that there was considerable correspondence between benthic measures and several groups of chemicals in the sediments. The chemical classes that were correlated with the benthic indices differed among the benthic endpoints. Most correlations were positive, while a few were negative.

First, both taxa richness and the SDI were negatively correlated with the concentrations of trace metals, whether normalized to the ERM, or SQS, or CSL values. The correlations with taxa richness were considerably stronger than those with the SDI values. Second, total abundance and taxa richness were highly correlated with the concentrations of PAHs in the samples. However, these correlations were positive, indicating that the abundance of the benthos and the numbers of species increased as the concentrations of PAHs increased. In addition, the abundance of annelids and molluscs showed the same patterns, i.e., increasing abundance with increasing PAH concentrations. In contrast, Pielou's index of evenness was negatively correlated with the concentrations of the PAHs, which is more consistent with what would be expected. The abundance of arthropods, echinoderms, and miscellaneous phyla were either not significantly correlated with chemical concentrations or, as in the case of the miscellaneous taxa, only weakly correlated with them.

Benthic Infauna Indices vs. Individual Chemical Chemicals

The benthic indices that co-varied to the greatest degree with trace metals concentrations (partial digestions) were total abundance, taxa richness, and annelid abundance (Table 26). As suggested with the correlations with trace metal concentrations normalized to the respective guidelines or criteria, the correlations between individual metals concentrations determined with partial digestions and taxa richness often were highly significant. This was especially apparent with a number of minor elements (i.e., aluminum, iron, magnesium, and sodium) that are not terribly toxic, but indicative of estuarine, fine-grained, depositional areas. Nevertheless, the correlations between taxa richness and the concentrations of potentially toxic metals (i.e., cadmium, chromium, nickel, selenium, and zinc) were highly significant. Curiously, whereas the abundance of annelids was not significantly correlated with mean guideline or criteria quotients for trace metals, the correlations with a number of individual elements (e.g., chromium, cobalt, nickel, and selenium) were highly significant. The abundance of molluscs was also highly correlated with concentrations of selenium. Total abundance of the benthos was highly correlated ($p \leq 0.0001$) with the concentrations of chromium, manganese, and nickel determined with partial digestions (Table 26).

The correlations between trace metals concentrations and benthic indices changed somewhat when the data from total digestions were analyzed (Table 27). The correlation coefficients often were slightly lower than with the partial digestion metals data and fewer correlations were highly significant. Nickel and selenium appeared to be significantly correlated with many benthic indices. Taxa richness was significantly correlated with cadmium, chromium, and selenium. Swartz's dominance index and the abundance of annelids and molluscs were correlated with two or three metals.

Pielou's evenness index was significantly negatively correlated with a number of the low molecular weight PAHs. Total abundance and mollusc abundance increased with increasing concentration of the sums of 6 LPAH, and dominance decreased slightly with increasing concentrations of many individual chemicals and the sums of 7 LPAH (Table 28). Total abundance, evenness, and dominance all showed about the same patterns with concentrations of high molecular weight PAHs (Table 29). Both the correlation coefficients and the benthic indices that were correlated with the concentrations of PAHs differed between the dry wt. normalized ERM classes and the organic carbon – normalized SQS/CSL classes of compounds. Evenness and dominance, in particular, were highly correlated with the HPAHs. In contrast, none of the correlations between PCB and DDT concentrations and the benthic indices was significant (Table 30).

None of the benthic indices was highly correlated ($p \leq 0.0001$) with the concentrations of any of the organotins, phenols, or miscellaneous substances (Table 31). However, Pielou's evenness index decreased as the concentrations of dibenzofuran increased. The chemical 9(H) carbazole also showed a slight negative correlation with both evenness and dominance. These two chemicals also showed significant correlations with Microtox™ and HRGS test results.

Summary

The majority of the benthic infaunal indices calculated were weakly or not significantly correlated with the sediment measures of percent fines and total organic carbon. The exceptions were taxa richness, Swartz's Dominance Index, and annelid abundance, which were moderately to highly negatively correlated with percent TOC. Correlations between amphipod survival and benthic indices were not significant, while results of the Microtox™ tests and HRGS assays showed highly significant correlations with indices of evenness and dominance. The abundance of miscellaneous taxa also decreased as HRGS induction increased. Taxa richness and the SDI were negatively correlated with the mean ERM and SQS quotients for trace metals, while total abundance, taxa richness, and the abundance of annelids and molluscs were highly positively correlated with mean ERM and SQS quotient of PAHs in the samples. The benthic indices that co-varied to the greatest degree (i.e., significant negative correlations) with individual trace metals concentrations were total abundance, taxa richness, and annelid abundance. Pielou's evenness and the SDI were significantly negatively correlated with a number of the LPAH and HPAH chemicals, while total abundance was positively correlated with these measures. In contrast, none of the correlations between PCB, DDT, organotins, and phenols concentrations and the benthic indices were significant. However, Pielou's evenness index decreased as the concentrations of dibenzofuran increased, and the chemical 9(H) carbazole also showed a slight negative correlation with both evenness and dominance. These two chemicals also showed significant correlations with Microtox™ and HRGS test results. All of these results, together, suggest that no single chemical or chemical class acting alone caused either the responses in the toxicity tests or the changes in benthic indices in these samples and changes in benthic indices could not be foretold with any single toxicity test.

Triad Synthesis: A Comparison of Chemistry, Toxicity, and Infaunal Parameters

To generate a more comprehensive picture of the quality of the sediments throughout the study area, a weight-of-evidence approach was used to simultaneously examine all three "sediment triad" parameters measured. Results from the toxicity testing, chemical analyses, and benthic community analyses from all stations were combined into one table (Appendix J). Included in this compilation are the chemicals measured at concentrations above the critical values (state standards, NOAA guidelines) and bioassay results indicative of a significant response. Benthic infaunal assemblages are represented in Appendix J by listing the nine infaunal indices generated for each station. In the absence of multimetric benthic index as used in EMAP studies, best professional judgment was used to evaluate the condition of the infaunal assemblages in this Puget Sound study. The suite of infaunal indices was examined for each station, and a determination was made as to whether the infaunal assemblage appeared to be adversely affected by unfavorable conditions, either natural or anthropogenic. Healthy assemblages typically displayed a combination of high total abundance, taxa richness, evenness, and dominance index values. Assemblages that appeared to be adversely affected by their surroundings typically displayed lower total abundance, taxa richness, evenness, and dominance values, although in some cases, total abundance in a sample was elevated due to large numbers of one or two species (e.g., pollution tolerant species). Appendix J was then reviewed to determine the number of significant triad results present at each station. This "weight-of-evidence" approach was used to define each station, based on the number of impaired parameters measured at each station.

Four categories of sediment quality were generated to define each station, including:

- High Quality (none of the sediment triad parameters impaired)
- Intermediate/High Quality (1 sediment triad parameter impaired)
- Intermediate/Degraded Quality (2 sediment triad parameters impaired)
- Degraded Quality (all of the sediment triad parameters impaired)

A summary of the total number of south Puget Sound stations with each of the four types of triad combinations for the south Puget Sound stations is displayed in Table 32 and depicted in Figures 27-30. There were 11 stations (4.4 km^2, 0.5% total study area) displaying sediment toxicity, chemical contamination, and altered benthos (i.e., "Degraded Quality"). These stations were located in Port Gamble Bay (stations 212, 214); the Port of Olympia (stations 243-244); and Thea Foss (stations 294-296), Middle (station 299), and Hylebos Waterways (stations 303-305) in Commencement Bay. All of these stations were shallow (3-14m, mean = 9 $\pm$ 3 s.d.), represent a small area (<0.1 to 1.4km^2, mean = 0.4 $\pm$ 0.5 s.d.), and with the exception of Port Gamble, all are located in major urban areas. Grain size at these stations was variable, ranging from 11 to

78% fines (mean = 58 ± 18 s.d.), but TOC values were high, ranging from 0.5-7.9%OC (mean = 2.8 ± 2.0 s.d.). Salinity ranged from 23-31ppt (mean = 29 ± 2.3 s.d.). Infaunal assemblages in, the majority of these 11 stations were characterized by variable total abundance (0-2924 individual, mean = 1038 ± 874 s.d.), taxa richness from 0 to 82 (mean = 52 ± 25 s.d.), evenness values from 0.0-0.77 (mean = 0.49 ± 0.20 s.d.), and Swartz's Dominance Index from 0 to 10 (mean = 4.5 ± 3.0 s.d.). The assemblages were dominated by annelids (0-2259 individuals, mean = 831 ± 709 s.d.), followed by molluscs (0-521 individuals, mean = 152 ± 171 s.d.), arthropods (0-119 individuals, mean = 41 ± 41 s.d.), echinoderms (0-41, mean = 9 ± 15 s.d.), and miscellaneous taxa (0-10 individuals, mean = 4 ± 3 s.d.). The polychaete species *Aphelochaeta* sp. N1 was the dominant taxon at ten of the eleven stations, while the station with the lowest salinity (station 294 in the Thea Foss Waterway) was dominated by the mollusc *Alvania compacta* and the polychaete *Capitella capitata* hyperspecies. The sediment from these 11 stations displayed a wide variety of chemical contaminants, reflective of the various types of anthropogenic activity in the surrounding areas. Mean ERM quotients ranged from 0.1 to 4.3 (mean = 1.0 ± 1.2 s.d.). All stations showed significant toxicity with the cytochrome P450 HRGS bioassay.

There were 36 stations (493.5 km^2, 57.5% total study area) with no toxicity or chemical contamination, and supporting abundant and diverse infaunal assemblages. These stations were located in Port Ludlow (station 208); northern (stations 209-211), central (stations 222-223), and southern (stations 224-226) Hood Canal; Quilcene Bay (stations 215-217); Dabob Bay (station 218); Totten and Eld Inlets (stations 234, 239); Pickering Passage/Squaxin Island (station 246); Henderson (station 248-249), Case (station 253) and Carr Inlets (stations 263-264); Nisqually Reach (station 254-256); Drayton (stations 258-259), Hale (stations 267-268), Colvos (stations 272-274), and East Passage (station 280); East Anderson Island/Cormorant Passage (station 261-262); Quartermaster Harbor (station 275); and Outer Commencement Bay (station 284). These stations typically included the larger, deeper inlets, basins, and passages of the more rural areas of south Puget Sound and Hood Canal, as well as a few smaller embayments. These stations represented areas in their respective strata that ranged in size from 0.9 to 36.4 km^2 (mean = 13.7 ± 11.5 s.d.), with depths ranging from 2 to 166m (mean = 57 ± 44 s.d.). Grain size at these stations was variable, ranging from 2 to 96% fines, but was typically coarser (mean = 39 ± 33 s.d.) than in the 11 degraded stations described above, while TOC values were lower, ranging from 0.06-4.2%OC (mean = 1.3 ± 1.1 s.d.). Salinity in these stations was similar to the 11 above, ranging from 23-32ppt (mean = 29 ± 2.2 s.d.). In comparison with the 11 stations with degraded sediment quality, infaunal assemblages in these 36 stations were characterized by lower total abundance (69 to 1574 individuals, mean = 426 ± 292 s.d.), similar taxa richness from 15 to 104 (mean = 58 ± 26 s.d.), higher evenness values from 0.51-0.92 (mean = 0.75 ± 0.10 s.d.), and higher Swartz's Dominance Index values ranging from 2 to 31 (mean = 14 ± 8 s.d.). Sediments at these stations were dominated by annelids (35-645 individuals, mean = 206 ± 142 s.d.), followed by arthropods (0-731 individuals, mean = 97 ± 139 s.d.), molluscs (4-427 individuals, mean = 85 ± 100 s.d.), echinoderms (0-380, mean = 26 ± 68 s.d.), and miscellaneous taxa (0-61 individuals, mean = 11 ± 11 s.d.). The assemblages at these stations with high quality sediments typically had lower numbers of annelids and higher numbers of arthropods and molluscs than the 11 stations with degraded sediments. The suite of dominant species at the stations with high quality sediments also differed from those with degraded sediments, and included the polychaetes *Levinsenia gracilis*, *Trochochaeta multisetosa*; the arthropods

Eudorella pacifica, Euphilomedes carcharodonta, Euphilomedes producta; the molluscs *Axinopsida serricata, Parvilucina tenuisculpta*; and the echinoderm *Amphiodia urtica/periercta* complex.

Thirty-five stations (274.1 km^2, 32.0% total study area) had one impaired sediment triad parameter (i.e., intermediate/high quality sediments), and included stations with characteristics similar to those with high quality sediments. Intermediate/high quality sediments were found in Port Gamble Bay (station 213); Dabob Bay (stations 219-220); central Hood Canal (station 221); Oakland Bay (stations 230-232); Totten (station 233), Eld (stations 238, 240), Budd (station 241), Henderson (station 250), Case (station 251-252), and Carr (station 265) Inlets; Pickering Passage/Squaxin Island (station 245, 247); Drayton (station 257) Hale (station 266), and East Passage (stations 278-279); Gig (station 271) and Quartermaster (station 276-277) Harbors; outer (stations 281-283), southeast (stations 285-286, 288-290), and northeast (stations 291-292) Commencement Bay; and Middle Waterway (station 298).

The remaining 18 stations (85.7km^2, 10.0% total study area) had two impaired sediment parameters (i.e., intermediate/degraded quality sediments), and included stations with characteristics similar to those with degraded sediments. Intermediate/degraded quality sediments were found in Port Ludlow (stations 206-207); the Port of Shelton (stations 227-229); Totten (station 235) and Budd (station 236-237) Inlets; the Port of Olympia (station 242); East Anderson Island/North Cormorant Passage (station 260); Gig Harbor (stations 269-270); southeast (station 287) and northeast (station 293) Commencement Bay; and Middle (station 297) and Blair (stations 301-302) Waterways.

Summary

A weight-of-evidence approach was used to simultaneously examine all three "sediment quality triad" parameters measured. This approach was used to define each station, based on the number of impaired parameters measured at each station. Four categories of sediment quality were generated, including "High Quality" (none of the sediment triad parameters impaired), "Intermediate/High Quality" (1 sediment triad parameter impaired), "Intermediate/Degraded Quality" (2 sediment triad parameters impaired), and "Degraded Quality" (all of the sediment triad parameters impaired). There were 11 stations (4.4 km^2, 0.5% total study area) with sediment toxicity, chemical contamination, and altered benthos (i.e., "Degraded Quality"). These stations were shallow, represented a small area, were primarily located in major urban areas, and had relatively fine grain size and high TOC values. Infaunal assemblages typically had higher total abundance (typically due to one or two abundant dominant organisms), moderate taxa richness and evenness, lower dominance values, and were dominated by annelids, sometimes in high abundance, followed by molluscs, arthropods, echinoderms, and miscellaneous taxa. The polychaete species *Aphelochaeta* sp. N1 was the dominant taxa at ten of the eleven stations, while the station with the lowest salinity (station 294 in the Thea Foss Waterway) was dominated by the mollusc *Alvania compacta* and the polychaete *Capitella capitata* hyperspecies. The sediment from these 11 stations displayed a wide variety of chemical contaminants, reflective of the various types of anthropogenic activity in the surrounding areas and all stations showed significant responses with the cytochrome P450 HRGS.

In contrast, 36 stations (493.5 km^2, 57.5% total study area) had no toxicity or chemical contamination, and abundant and diverse infaunal assemblages. These stations typically included the larger, deeper inlets, basins, and passages of the more rural areas of south Puget Sound and Hood Canal, as well as a few smaller embayments. They tended to have coarser sediment with lower TOC content than those stations with degraded sediment quality. Infaunal assemblages at these stations had lower total abundance, and higher evenness and dominance values than those stations with degraded sediment quality. The assemblages at these stations typically had lower numbers of annelids and higher numbers of arthropods and molluscs than stations with degraded sediments, and a different suite of dominant species.

Thirty-five stations (274.1 km^2, 32.0% total study area) had one impaired sediment triad parameter (i.e., intermediate/high quality sediments), and included stations with characteristics similar to those with high quality sediments. The remaining 18 stations (85.7km^2, 10.0% total study area) displayed two impaired sediment parameters (i.e., intermediate/degraded quality sediments), and included stations with characteristics similar to those with degraded sediments.

Discussion

Spatial Extent of Toxicity

The survey of sediment toxicity in southern Puget Sound was similar in intent and design to those performed elsewhere by NOAA in many different bays and estuaries in the U. S. (Long et al., 1996). Using methods comparable to those used in the survey of southern Puget Sound, NOAA and U. S. EPA have developed data for areas along the Atlantic, Gulf of Mexico, and Pacific coasts to determine the presence, severity, regional patterns and spatial scales of toxicity (Long et al., 1996; Long, 2000). Spatial extent of toxicity in other regions ranged from 0.0% of the area to 100% of the area, depending upon the toxicity test. However, data equivalent to those developed in this survey have not been generated previously in Puget Sound, therefore comparisons with earlier surveys are not feasible.

All aspects of the study design of this survey were the same as those for the surveys of northern and central Puget Sound, including methods for sample collections, sample analyses, and data interpretations (Long et al., 1999a, 2000). The intent of the three surveys was to provide information on sediment quality throughout all regions of the study area, including a number of urbanized/industrialized areas. This survey was not intended to focus upon any existing or likely point source of toxicants. Therefore, the survey area was very large and complex. The data from the laboratory bioassays were intended to represent the toxicological condition of the survey area, using a battery of complementary tests with different endpoints. Data from chemical analyses were generated to characterize the chemical characteristics of samples. Benthic community analyses were performed to determine if significant toxicological results in the laboratory were also apparent in the resident biota in the field. The primary objectives were to estimate the severity, spatial patterns, and spatial extent of toxicity, chemical contamination and changes in benthic community structure. A stratified-random design was followed to ensure that unbiased sampling was conducted and, therefore, the data could be attributed to the strata within which samples were collected.

Four different toxicity tests were performed on all the sediment samples. All tests showed some degree of differences in results among the test samples and negative controls. All showed spatial patterns in toxicity that were unique to each test, but, also overlapped to varying degrees with results of other tests. There were no two tests that showed duplicative results.

Comparisons of toxicity test results among the three regions of the Sound indicated several different patterns (Table 33). Highly toxic conditions were apparent in only one of the 300 samples tested for amphipod survival, thus, no spatial patterns were evident with the data from that test. The urchin and Microtox™ tests indicated that toxicity was slightly more widespread in northern and southern regions of the Sound and least pervasive in the central region. The cytochrome P450 HRGS assay indicated that significant and highly significant responses were more widespread in the central and southern regions. Therefore, based upon the data from the three most sensitive tests, it appears that toxicity was slightly more widespread in the southern region than in the other two.

Based upon the combined data from all three regions, the entire survey encompassed approximately 2363 km^2 of Puget Sound (Table 33). The strata in which highly significant responses were observed represented 0.04% of the area in the amphipod survival tests (i.e., control-adjusted survival <80%) and 0.4% of the area in the Microtox™ tests (i.e., EC50 <0.51 mg/ml). In the sea urchin tests, the overall spatial extent of toxicity represented 4%, 0.7%, and 0.6% of the combined area in tests of the three porewater concentrations. In the HRGS assays, samples with responses >11.1 ug/g and >37.1 ug/g represented 24.8% and 2.8%, respectively, of the combined area. Thus, based upon the criteria for highly significant responses in each of the four tests, the overall spatial extent of toxicity was very small throughout the combined Puget Sound study area, ranging from 0.04% to 4% in the four tests.

Amphipod Survival – Solid Phase

These tests of relatively unaltered, bulk sediments were performed with juvenile stages of crustaceans exposed to the sediments for 10 days. The endpoint was survival. Data from several field surveys conducted along portions of the Pacific, Atlantic, and Gulf of Mexico coasts have shown that significantly diminished survival of these animals often is coincident with decreased benthic resources. In particular, losses in total abundance of benthos, abundance of crustaceans (including amphipods), total species richness, and other metrics of benthic community structure often occur in samples classified as toxic in these tests (Long et al., 2001). Therefore, this test often is viewed as having relatively high ecological relevance. In addition, it is the most frequently used test nationwide in assessments of dredging material and hazardous waste sites.

The amphipod tests proved to be the least sensitive of the tests performed in southern Puget Sound. Of the 100 samples tested, survival was significantly different from controls in 3 samples. Samples in which test results were significant were collected at stations widely scattered throughout the study area. The data showed no spatial pattern or gradient in response among contiguous stations or strata. Control-adjusted survival was 81%, 90%, and 92% in the three statistically significant samples. Therefore, none of the samples was classified as "highly toxic". The incidence of statistically significant toxicity in these samples (3%) was somewhat lower than observed in central Puget Sound in 1998 (7%) and in northern Puget Sound in 1997 (13%). Overall, the combined incidence of significant toxicity was 7.7% (23 of 300 samples) for all three years.

The results in the amphipod tests performed in Puget Sound differed from results of comparable studies conducted elsewhere in the U.S. Whereas amphipod survival was less than 80% of controls in 12.4% of samples from studies performed elsewhere (n=2630; Long, in press), only one of the samples from central Puget Sound showed survival that low. None of the northern Puget Sound samples and none from the southern region indicated survival of less than 80% of controls.

With the results of the amphipod tests weighted to the sizes of the sampling strata within which samples were collected, the spatial scales of toxicity were estimated and expressed as percentage of the study area. A critical value of <80% of control response was used to estimate the spatial extent of toxicity in this test. However, because none of the test samples indicated less than 80% survival relative to controls in southern Puget Sound, the spatial extent of toxicity was estimated as 0% of the southern region of the survey area.

To add perspective to these data, the results from southern, central and northern Puget Sound were compared to those from other estuaries and marine bays surveyed by NOAA in the U.S. The methods for collecting and testing the samples for toxicity were comparable to those used in the Puget Sound surveys (Long et al., 1996; Long, 2000). In surveys of 27 U. S. regions, estimates of the spatial extent of toxicity ranged from 0.0% in many areas to 85% in Newark Bay, NJ (Table 34). The three regions of Puget Sound were among the many survey areas in which the spatial extent of toxicity in the amphipod tests was estimated to be 0% to 0.1%. With the data compiled from studies conducted through 1997, the samples that were classified as toxic represented about 5.9% of the combined area surveyed. The data for all three regions of Puget Sound fell well below the national average. These data suggest that acute toxicity as measured in the amphipod survival tests was neither severe nor widespread in these regions of Puget Sound.

Sea Urchin Fertilization - Pore Water

Early life stages of invertebrates often are more sensitive to toxicants than adult forms, mainly because fewer defense mechanisms are developed in the gametes than in the adults (Carr, 1997). The test endpoint - fertilization success - is a sublethal response expected to be more sensitive than the acute mortality response recorded in the amphipod tests. The gametes were exposed to the pore waters extracted from the samples; the phase of the sediments in which toxicants were expected to be highly bioavailable. This test was adapted from protocols for bioassays originally performed to test wastewater effluents and has had wide application throughout North America in tests of both effluents and sediment pore waters. The combined effects of these features was to develop a relatively sensitive test - much more sensitive than that performed with the amphipods exposed to solid phase sediments.

Urchin fertilization was less than 80% of controls in southern Puget Sound samples that represented 5.7% of the area with tests of 100% pore water, 0.5% with tests of 50% pore water, and 0.3% with tests of 25% pore water. These estimates are roughly equal to those calculated for the northern Puget Sound area where the estimated percentages were 5.2%, 1.5% and 1.1% of the total, respectively. In central Puget Sound, the spatial extent of toxicity totaled about 0.5%, 0.2%, and 0.6% of the total area in tests of the three porewater concentrations, respectively. Therefore, conditions as estimated in this test were roughly equivalent in the southern and northern regions and somewhat less toxic in the central region.

NOAA estimated the spatial extent of toxicity in urchin fertilization or equivalent tests performed with 100% pore water in many other regions of the U. S. (Long et al., 1996). These estimates ranged from 98% in San Pedro Bay (CA) to 0.0% in Leadenwah Creek (SC) (Table 35). As in the amphipod tests, all three regions of Puget Sound ranked near the bottom of this range, well below the "national average" of 25% calculated with data accumulated through 1997. Equivalent results in this test were reported in areas such as St. Simons Sound (GA), St. Andrew Bay in western Florida, and Leadenwah Creek (SC), in which urbanization and industrialization were restricted to relatively small portions of the estuaries. Therefore, as with the amphipod tests, these tests indicated that acute toxicity was neither widespread nor severe in Puget Sound sediments.

Microbial Bioluminescence (Microtox™) - Organic Solvent Extract

The Microtox™ tests were performed with organic solvent extracts of the sediments. These extracts were intended to elute all potentially toxic organic substances from the sediments regardless of their bioavailability. The tests, therefore, provide an estimate of the potential for toxicity attributable to complex mixtures of toxicants associated with the sediment particles, and, not normally available to benthic infauna. This test is not sensitive to the presence of ammonia, hydrogen sulfide, fine-grained particles or other features of sediments that may confound results of other tests. The test endpoint is a measure of metabolic activity, not acute mortality. These features combined to provide a relatively sensitive test - usually the most sensitive test performed nationwide in the NOAA surveys (Long et al., 1996).

In northern Puget Sound (Long et al., 1999), the data were difficult to interpret because of the unusual result in the negative control sample from Redfish Bay (TX). Test results for the control showed the sample to be considerably less toxic relative to previous tests of sediments from that site and to tests of negative control sediments from other sites used in previous surveys. Therefore, new analytical tools were generated with the compiled NOAA data to provide a meaningful critical value for evaluating the northern Puget Sound data.

Using a critical EC50 value of <0.51 mg/ml, it was estimated that the spatial extent of toxicity in the northern Puget Sound represented 1.2% of the survey area. The estimate for central Puget Sound (0% of the area) was less than the estimate for northern Puget Sound. For the southern region, the estimate was 0.2% of the area. These estimates ranked northern, central, and southern Puget Sound at the bottom of the distribution for data generated from 19 bays and estuaries surveyed by NOAA (Table 36). Also, they were considerably less than the estimate for the combined national estuarine average of 39% calculated with data compiled through 1997.

Human Reporter Gene System (Cytochrome P450) Response - Organic Solvent Extract

This test is intended to identify samples in which there are elevated concentrations of mixed-function oxygenase inducing organic chemicals, notably the dioxins and higher molecular weight PAHs. It is performed with a cultured cell line that provides very reliable and consistent results. Tests are conducted with an organic solvent extract to ensure that potentially toxic organic chemicals are eluted. High cytochrome P450 HRGS induction may signify the presence of substances that could cause or contribute to the induction of mutagenic and/or carcinogenic responses in local resident biota (Anderson et. al., 1995, 1996).

In central Puget Sound, the cytochrome P450 HRGS assay indicated that samples in which results exceeded 11.1 and 37.1 μg/g B(a)P equivalents represented approximately 32.3% and 3.2%, respectively, of the total survey area. In the southern region, results were roughly equivalent to those for the central region (i.e., 38.4% and 5.0%). In contrast, the equivalent estimates for northern Puget Sound were much lower at 2.6% and 0.03% of the study area (Long et al., 1999a). Therefore, toxicity estimated with this test was most widespread in the central and southern regions and least widespread in the northern region. Relatively high responses were recorded in many samples from large strata sampled in central Puget Sound, thereby resulting in larger estimated areas. In northern Puget Sound the samples with elevated responses were collected primarily in the small strata in Everett Harbor. In the southern region, samples that provided the highest responses were collected in Budd Inlet, Commencement Bay and several of its adjoining waterways.

These tests were performed in NOAA surveys in 9 areas where estimates of spatial extent could be made: northern, central, and southern Puget Sound (WA), northern Chesapeake Bay (MD), Sabine Lake (TX), Biscayne Bay (FL), Delaware Bay (DE), Galveston Bay (TX), and a collection of Southern California coastal estuaries (CA). Based upon the critical values of 11.1 and 37.1μg/g, the samples from central and southern Puget Sound ranked near the middle of the distribution for areas in which there are equivalent data (Table 37). The HRGS responses greater than 11.1 μg/g represented the largest percent of study area toxic in samples from northern Chesapeake Bay, Southern California estuaries, southern Puget Sound, then central Puget Sound. Responses greater than 37.1 μg/g represented the largest percent of study area toxic in northern Chesapeake Bay, followed by southern Puget Sound, Delaware Bay, then central Puget Sound. In both the central and southern Puget Sound areas, HRGS responses greater than 11.1 μg/g were more widespread than in the combined national average (20%), whereas Puget Sound responses greater than 37.1 μg/g were less widespread than the national average of 9.2%.

Responses among the 100 samples from southern Puget Sound ranged from 1.5 to 1994.9 μgB[a]Peq/g. There were 17 samples with responses >37.1 ug/g. In central Puget Sound, HRGS assay responses ranged from 0.4 μg/g to 223 μg/g and there were 27 samples in which the responses exceeded 37.1 μg/g. In northern Puget Sound, responses ranged from 0.3 μg/g to 104.6 μg/g and only four samples had responses greater than 37.1 μg/g. In analyses of 30 samples from Charleston Harbor and vicinity, results ranged from 1.8 μg/g to 86.3 μg/g B[a]p equivalents and there were nine samples with results greater than 37.1 μg/g. In the 121 samples from Biscayne Bay, results ranged from 0.4 to 37.0 μg/g B[a]p equivalents. Induction responses in 30 samples from San Diego Bay were considerably higher than those from all other areas. Assay results ranged from 5 μg/g to 110 μg/g B[a]p equivalents and results from 18 samples exceeded 37.1 μg/g in San Diego Bay. Responses in eight samples exceeded 80 μg/g.

The percentages of samples from different survey areas with cytochrome P450 HRGS responses greater than 37.1 μg/g were: 60% in San Diego Bay, 30% in Charleston Harbor, 27% in central Puget Sound, 23% in Delaware Bay, 17% in southern Puget Sound, 11% in Sabine Lake, 4% in northern Puget Sound, 1% in Galveston Bay, and 0% in both Biscayne Bay and Southern California estuaries. Based upon data from all NOAA surveys (n=693, including central and northern Puget Sound), the average and median HRGS assay responses were 23.3 μg/g and 6.7 μg/g, somewhat lower than observed in central Puget Sound - average of 37.6 μg/g and median of 17.8 μg/g.

The data from these comparisons suggest that the severity and spatial extent of enzyme induction determined in the HRGS test on central and southern Puget Sound samples were roughly equivalent to those determined as the national average. There were several survey areas in which toxicity was more severe and widespread and several areas in which it was less so. The responses were clearly more elevated than those in samples from northern Puget Sound.

In all three regions of Puget Sound, the HRGS assay results showed highly significant correlations with the concentrations of PAHs in the samples. The highest responses in these assays focused attention upon samples from Everett Harbor, the lower Duwamish River/inner Elliott Bay, and the industrial waterways of Commencement Bay. Follow-up experimentation with extracts from selected samples collected in these three industrialized areas was done to identify whether PAHs or dioxins and dioxin-like chlorinated chemicals were causing the elevated responses. The experiments indicated that dioxins were important contributors to the HRGS induction in samples from Everett Harbor, whereas the PAHs appeared to be most important in samples from Elliott and Commencement Bays.

Levels of Chemical Contamination

There were 9 samples from southern Puget Sound, representing about 1% of the survey area, in which one or more ERM values were exceeded for all substances measured (excluding nickel) (Table 38). In comparison, there were 17 and 10 samples in which one or more SQS or CSL values, respectively, were exceeded (>QL only). Those samples represented about 7% and 5%, respectively, of the southern survey area. In central Puget Sound, there were 21 samples in which one or more ERM values were exceeded for all chemicals measured (excluding nickel). These samples represented an area of about 1.6 % of the total survey area. There were 93 samples with at least one chemical concentration greater than an SQS value (91.4% of the area) and 92 samples with at least one concentration greater than a CSL value (99.3%) of the area (>QL only). In northern Puget Sound, there were 9 samples representing about 9.5 km^2 (or 1.2% of the total area) in which one or more ERMs were exceeded for all chemicals measured (excluding nickel). There were 71 samples with at least one chemical concentration greater than an SQS value (68.5% of the area) and 58 samples with at least one concentration greater than a CSL value (56.1%) of the area (>QL only). A large proportion of the samples form the northern and central regions were classified as contaminated due to the presence of elevated concentrations of benzoic acid, 4-methylphenol and phenol.

In Biscayne Bay, 33 of 226 samples (15%) representing about 0.7% of the study area had equivalent chemical concentrations (Long et al., 1999b). In selected small estuaries and lagoons of Southern California, 18 of 30 randomly chosen stations, representing 67% of the study area, had chemical concentrations that exceeded one or more Probable Effects Level (PEL) guidelines (Anderson et al., 1997). In the combined NOAA/EPA database, 27% of samples had at least one chemical concentration greater than the ERM (Long et al., 1998). In the Carolinian estuarine province, Hyland et al. (1996) estimated that the surficial extent of chemical contamination in sediments was about 16% relative to the ERMs. In data compiled from three years of study in the Carolinian province, however, the size of the area with elevated chemical contamination decreased to about 5% (Dr. Jeff Hyland, NOAA, pers. comm.). In data compiled by Dr. Hyland from stratified-random sampling in the Carolinian province, Virginian province, Louisianian province, northern Chesapeake Bay, Delaware Bay, and DelMarVa estuaries, the estimates of the spatial extent of contamination in which one or more ERM values were exceeded ranged from about 2% to about 8%.

The four samples from the Commencement Bay waterways in which mean ERM quotients were greater than 1.0 represented 0.6 km^2 or 0.07% of the southern survey area. In central Puget Sound, there were 11 samples in which the mean ERM quotients exceeded 1.0. These samples represented an area of 3.6 km^2, or about 0.5% of the total survey area. In the northern Puget Sound study, none of the mean ERM quotients for 100 samples exceeded 1.0. In comparison, 6 of 226 samples (3%) from Biscayne Bay, FL, had mean ERM quotients of 1.0 or greater (Long et al., 1999b). Among 1068 samples collected by NOAA and EPA in many estuaries nationwide, 51 (5%) had mean ERM quotients of 1.0 or greater (Long et al., 1998).

Collectively, the chemical data indicate that most of the southern Puget Sound sediment samples were not highly contaminated. Relative to effects-based guidelines or standards, relative to previous Puget Sound studies, and relative to data from other areas in the U.S; the concentrations of most trace metals, most PAHs, total PCBs, and most chlorinated pesticides were not very high in the majority of the samples. However, the concentrations of nickel, mercury, some phenols some phthalates, benzoic acid, PAHs, and PCBs were relatively high in some samples.

The highest concentrations of mixtures of potentially toxic chemicals primarily occurred in samples from the waterways of Commencement Bay. In central Puget Sound, highly contaminated samples were observed in parts of the Duwamish River/Elliott Bay and Sinclair Inlet, the two most highly urbanized and industrialized bays within the 1998 study area. Similarly, the sediments analyzed during the 1997 survey of northern Puget Sound indicated that chemical concentrations were highest in Everett Harbor, which was one of the most urbanized bays in that survey.

Toxicity/Chemistry Relationships

It was not possible to identify and confirm which chemicals caused toxic responses in the urchin fertilization, Microtox™, and HRGS tests in the samples from Puget Sound. Conclusive determinations of causality would require extensive toxicity identification evaluations and spiked sediment bioassays. However, the chemical data were analyzed to determine which chemicals might have contributed to toxicity.

Typically in surveys of sediment quality nationwide, NOAA has determined that complex mixtures of trace metals, organic chemicals, and occasionally ammonia showed strong statistical associations with one or more measures of toxicity (Long et al., 1996). Frequently, as a result of the toxicity/chemistry correlation analyses, some number of chemicals will show the strongest associations leading to the conclusion that these chemicals may have caused or contributed to the toxicity that was observed. However, the strength of these correlations can vary considerably among study areas and among the toxicity tests performed.

In all three phases of the Puget Sound survey, the data were similar to those collected in several other regions (e.g., the western Florida Panhandle, Boston Harbor, and South Carolina/Georgia estuaries). Severe toxicity in the amphipod tests was either not observed in any samples or was very rare, and, therefore, correlations with toxicity were not significant or were weak. However, correlations with chemical concentrations were more readily apparent in the results of the sublethal tests, notably tests of urchin fertilization and microbial bioluminescence as in Puget Sound.

The strong statistical correlations between the HRGS response and the concentrations of PAHs and other organic substances in the 1999 Puget Sound samples were similar to what was observed in the 1997 and 1998 phases of this survey. Therefore, there appears to be a consistent response with this test among the three study areas, suggesting that complex mixtures of organic substances were driving the response. Furthermore, the highly significant correlations between enzyme induction in the HRGS assays and the concentrations of PAHs normalized to effects-based guidelines or criteria suggest that these substances occurred at sufficiently high concentrations to contribute to the responses. In contrast, the Microtox™ tests indicated strong correlations with mixtures of chemical concentrations in northern and southern Puget Sound, but much weaker or no significant correlations in the central region.

The sea urchin tests performed on pore waters extracted from the sediments and the Microtox™ and HRGS tests performed on solvent extracts showed overlapping, but different, spatial patterns in toxicity in all three regions of Puget Sound. Because of the nature of these tests, it is reasonable to assume that they responded to different substances in the sediments. The strong statistical associations between the results of the HRGS tests and the mean ERM quotients for 25 substances provides evidence that mixtures of contaminants co-varying in concentrations could have contributed to these responses.

Whereas the urchin fertilization tests showed strong correlations with chemical concentrations in central Puget Sound, these relationships were much weaker in northern and southern Puget Sound. Percent sea urchin fertilization was highly correlated (rho = -0.518, $p<0.0001$) with the mean ERM quotients for 25 substances and most of the individual classes of substances in central Puget Sound. These correlations with mean ERM quotients (rho =-0.294, $p<0.01$) and classes of substances (ranging from not significant to significant at rho =-0.244, $p<0.05$) were weaker in northern region samples. In the southern region samples, urchin fertilization also showed weak associations with mean ERM quotients (rho =-0.300, $p<0.05$) and most classes of substances (ranging from not significant to significant at rho = –0.362, $p<0.01$). Correlations between percent urchin fertilization and mean SQS quotients for sums of 15 PAHs were -0.656 ($p<0.0001$) in the central region -0.338 ($p<0.05$) in the southern region, and +0.087 ($p>0.05$) in the northern region. However, in 15 samples from Everett Harbor and Port Gardner Bay, the correlation was very significant (rho =-0.788, $p<0.001$, n=15).

The data showed that urchin fertilization was weakly associated ($p<0.05$) with several trace metals (notably arsenic, copper, lead, mercury, tin and zinc) in northern and central Puget Sound, but not in the southern region. Some of these metals occurred at concentrations above their respective ERL and SQS levels in northern and central region samples. The correlation coefficients for mean SQS quotients for 8 trace metals and percent urchin fertilization in northern, central, and southern regions were -0.319 ($p<0.05$), -0.557 ($p<0.05$), and -0.178 ($p>0.05$), respectively. Similarly, fertilization success was strongly correlated with the concentrations of PCBs in both central and northern Puget Sound, but not in the southern region. However, urchin fertilization was highly correlated with the concentrations of both high and low molecular weight PAHs in central Puget Sound, weakly correlated ($p<0.01$) with them in the southern region samples, but not in northern Puget Sound.

Because the solvent extracts would not be expected to elute trace metals, Microtox™ and HRGS results were expected to show strong associations with concentrations of PAHs and other organic chemicals. The data indicated that microbial bioluminescence decreased with increasing concentrations of most individual PAHs and most PCB congeners in the northern and southern samples, but not in the central region samples. Microtox™ results were correlated with benzoic acid and 4-methylphenol in the northern samples and carbazole and dibenzofuran in the northern and southern regions.

There were very few similarities among the three studies in the correlations between benthic indices and toxicity results. Results of the amphipod survival tests were not correlated with any benthic index in all three regions of the study. The highly significant correlation between echinoderm abundance and urchin fertilization in northern Puget Sound was not observed in the other two regions. Instead, urchin fertilization was correlated with annelid abundance in the central region and miscellaneous taxa abundance in the southern region. Microtox™ EC50's were positively correlated with taxa richness and Swartz's dominance index in all three regions, although at different probability levels. However, the highly significant correlation between Microtox™ results and Pielou's index observed in the southern region was not observed elsewhere.

The significant correlations between cytochrome P450 HRGS induction and both Pielou's Evenness Index and Swartz's dominance index was positive in the northern region and negative in central and southern sediments. Conversely, HRGS induction was negatively correlated with total abundance in the northern region, whereas the correlations were positive in the central and southern regions.

There were a few similarities among the three study areas in the relationships between benthic indices and chemical concentrations, but there were more differences. For example, the data consistently indicated highly significant correlations between the guideline or criteria-normalized concentrations of trace metals and taxa richness in all three areas. Also, Swartz's Dominance Index was highly correlated with trace metals and mean ERM quotients for 25 substances in all three regions. The abundance of molluscs was positively correlated with the SQS-normalized concentrations of LPAHs in all three regions. Mollusc abundance also was positively correlated with HPAHs in the southern region. This correlation was much weaker in the central region and not significant in the northern region. The abundance of annelids was positively correlated with CSL-normalized concentrations of PAHs in the northern and southern regions, but this correlation was negative in the central region.

The consistent relationships (i.e., observed in all three regions) between the concentrations of sediment-sorbed trace metals and both the numbers of species in the samples and the dominance index suggests that benthic infaunal species gradually were lost as trace metals concentrations increased. However, most of the benthic/chemical correlations were inconsistent among the three regions. The strong positive correlations between the abundance of both annelids and molluscs and the PAHs observed in the central and southern regions suggests that these animals were tolerant of the PAHs and attracted to the sampling areas by other ecological factors. However, these relationships were not apparent in the northern region.

Although the chemicals for which analyses were performed may have caused or contributed to the measures of toxicity and/or benthic alterations, other substances for which no analyses were conducted also may have contributed. Definitive determinations of the actual causes of toxicity in each test would require further experimentation. Similarly, the inconsistent relationships between measures of toxicity and indices of benthic structure suggest that the ecological relevance of the toxicity tests differed among the three regions of Puget Sound.

Benthic Community Structure, the "Triad" Synthesis, and the Weight-of-Evidence Approach

The abundance, diversity, and species composition of marine infaunal communities vary considerably from place to place and over both short and long time scales as a result of many natural and anthropogenic factors (Reish, 1955; Nichols, 1970; McCauley et al., 1976; Pearson and Rosenberg, 1978; Dauer et al., 1979; James and Gibson, 1979; Bellan-Santini, 1980; Gray, 1982: Becker et al., 1987; Ferraro et al., 1991; Llansó et. al.,1998b). Major differences in benthic communities can result from wide ranges in water depths, oxygen concentrations at the sediment-water interface, sediment texture (grain size), geochemical composition of the sediment particles, water salinity as a function of proximity to a river or stream, bottom water current velocity or physical disturbance as a result of natural scouring or maritime traffic, and the effects of predators. In addition, the composition of benthic communities at any single location can be a function of seasonal or inter-annual changes in larval recruitment, availability of food, proximity to adult brood stock, predation, and habitat characteristics.

In the survey of southern Puget Sound, samples were collected in the deep waters of the central basin (East Passage) and Hood Canal, in protected waters of several shallow embayments and coves, in scoured channels with strong tidal currents, and in the lower reaches of the highly industrialized Puyallup River. As a result the abundance, composition, and diversity of benthic communities would be expected to differ considerably from place to place.

Analyses of the benthic macroinfauna in the southern Puget Sound survey indicated that the vast majority of samples were populated by abundant and diverse infaunal assemblages. The numbers of species and organisms varied considerably among sampling locations, indicative of the natural degree of variability in abundance, community structure, and diversity among benthic samples in Puget Sound. The variability in benthic data for the southern region was equivalent to the ranges observed in the northern and central regions. Calculated indices of evenness and dominance showed variability equal to that for species counts and abundance. With huge ranges in abundance, species composition, and diversity as a result of natural environmental factors, it is difficult to discern the differences between degraded and un-degraded (or "healthy") benthic assemblages. Some benthic assemblages may have relatively low species richness and total abundance as a result of the effects of some natural environmental factors. There were a number of stations in all three regions in which the benthos was very abundant and diverse despite the presence of high chemical concentrations and/or high toxicity.

Both Long (1989) and Chapman (1996) provided recommendations for graphical and tabular presentations of data from the Sediment Quality Triad (i.e., measures of chemical contamination, toxicity, and benthic community structure). The triad of measures was offered as an approach for developing a weight-of-evidence to classify the relative quality of sediments (Long, 1989). Chapman (1996) later suggested that locations with chemical concentrations greater than effects-based guidelines or standards, and evidence of acute toxicity in laboratory tests (such as with the amphipod survival bioassays), and alterations to resident infaunal communities constituted "strong evidence of pollution – induced degradation". As a corollary, he suggested that there was "strong evidence against pollution-induced degradation" at sites lacking contamination, toxicity, and benthic alterations. Several other combinations were described in which mixed or conflicting results were obtained. In some cases, sediments could appear to be contaminated, but not toxic, either with or without alterations to the benthos or in which sediments were not contaminated with measured substances, but, nevertheless, were toxic, either with or without benthic alterations. Plausible explanations were offered for benthic "alterations" at non-contaminated and/or non-toxic locations possibly attributable to natural factors, such as those identified above.

When applied to the 1999 southern Puget Sound sediment data, the weight-of-evidence approach identified 11 stations (4.4 km^2, 0.5% total study area) displaying sediment toxicity, chemical contamination, and altered benthos (i.e., "Degraded Quality" sediments, "strong evidence of pollution-induced degradation"). In contrast, 36 stations (493.5 km^2, 57.5% total study area) displayed no toxicity or chemical contamination, and abundant and diverse infaunal assemblages (i.e., "High Quality" sediments, "strong evidence against pollution-induced degradation"). Thirty-five stations (274.1 km^2, 32.0% total study area) had one impaired sediment triad parameter (i.e., "Intermediate/High Quality" sediments), and the remaining 18 stations (85.7km^2, 10.0% total study area) displayed two impaired sediment parameters (i.e., "Intermediate/Degraded Quality" sediments).

Comparison of the results of the weight-of-evidence sediment quality triad analyses for this 1999 southern Puget Sound survey was made with both the 1997 and 1998 PSAMP/NOAA sediment surveys conducted in northern and central Puget Sound, respectively (Long et al. 1999a, 2000). Results are presented in Table 39.

Throughout Puget Sound, 42 of the 300 stations sampled (14%) displayed sediment toxicity, chemical contamination, and altered benthos (i.e., "Degraded Quality" sediments, "strong evidence of pollution-induced degradation"). These stations represented 35.1 km^2, or 1.5% of the 3-year study area. Central Puget Sound had the greatest number of these degraded quality stations (21, 20.4 km^2, 2.8% of central study area), while there were 10 in northern (10.3 km^2, 1.3% of study area) and 11 in southern (4.4 km^2, 0.5% of study area) Puget Sound. As seen in the 1999 data, stations throughout Puget Sound which displayed degraded sediment quality represented a small area (0.02-9.65 km^2, mean = 0.8 $\pm$ 1.6 standard deviation), shallow (3-122m, mean = 20 $\pm$ 25 standard deviation) embayments located primarily in major urban settings, including Everett Harbor and Port Gardner; Sinclair and Dyes Inlets; Port Washington Narrows; Elliott Bay and the Duwamish; Port Gamble; the Port of Olympia; and the Thea Foss, Middle, and Hylebos Waterways. The majority of these stations had relatively fine grain size (11-96% fines, mean = 69 $\pm$ 20 standard deviation) and high TOC (0.52-9.91%TOC, mean = 3.3$\pm$ 2.2 standard deviation) values. Infaunal assemblages typically had higher total abundance values (0-3764, mean = 892 $\pm$ 756 standard deviation)(typically due to large numbers of one or two dominant taxa), moderate taxa richness (0-93 taxa, mean = 45 $\pm$ 22 standard deviation) and evenness (0-0.82, mean = 0.53 $\pm$ 0.17 standard deviation), and low dominance values (0-16 SDI, mean = 4.6 $\pm$ 3.1 standard deviation). They were typically dominated by annelids, a few taxa often in extremely high abundance, followed by molluscs, arthropods, echinoderms, and miscellaneous taxa. The polychaete species *Aphelochaeta* sp. N1, *Aphelochaeta monilaris*, *Capitella capitata* hyperspecies, and *Scoletoma luti*; the mollusc *Axinopsida serricata;* the arthropod *Eudorella pacifica*, *Euphilomedes carcharodonta*, *Nebalia pugettensis* complex, and *Pinnixa schmitti*; and other species dominated the infaunal assemblage at many of these stations. The sediment from these stations displayed a wide variety of chemical contaminants and toxic responses, reflective of the various types of anthropogenic activity in the surrounding areas.

Throughout Puget Sound, 64 of the 300 stations sampled (21.3%) displayed no toxicity or chemical contamination, and abundant and diverse infaunal assemblages (i.e., "High Quality" sediments, "strong evidence against pollution-induced degradation"). These stations represented 764.9 km^2, or 32.4% of the 3-year study area. Southern Puget Sound had the greatest number of these high quality stations (36, 493.5 km^2, 57.5% of southern study area), while there were 26 in northern (211.9 km^2, 27.4% of study area) and only 2 in central (59.5 km^2, 8.1% of study area) Puget Sound. There were, however, 23 stations in central Puget Sound that would have fallen in this category but had one chemical, benzoic acid, above state sediment criteria. As seen in the 1999 data, stations throughout Puget Sound which displayed high sediment quality typically included the larger (0.84-52.94 km^2, mean = 12.0 $\pm$ 11.5 standard deviation), deeper (2 - 170m, mean = 48 $\pm$ 47 standard deviation) inlets, basins, and passages of the more rural areas of Puget Sound and Hood Canal. These stations were located in Semiahmoo, West Boundary, Bellingham, Samish, Fidalgo, and Skagit Bays; March Point; South Saratoga Passage; Port Susan; Possession Sound; Port Gardner; the Snohomish River Delta; Port Townsend; South Admiralty Inlet; Port Ludlow; Hood Canal; Quilcene and Dabob Bays; Totten, Eld, Henderson, Case, and Carr Inlets; Pickering Passage/Squaxin Island; Nisqually Reach; Drayton, Hale, East Anderson Island/No.Cormorant, Colvos, and East Passages; Quartermaster Harbor; and Commencement Bay. A few of these stations, however, were located close to urban areas in Bellingham Bay. These stations with "high quality" sediments tended to have coarser sediment (<1-102 % fines, mean = 45 $\pm$ 37 standard deviation), with lower TOC (0.06-4.20% TOC, mean = 1.21 $\pm$ 1.00 standard deviation) content than those stations with degraded sediment quality. Infaunal assemblages at these stations had lower total abundance (24-5125, mean = 734 $\pm$ 982 standard deviation), moderate taxa richness (6-104 taxa, mean = 55 $\pm$ 24 standard deviation), and higher evenness (0.25-0.92, mean = 0.71 $\pm$ 0.14 standard deviation) and dominance values (1-31 SDI, mean = 12 $\pm$ 8 standard deviation) than those stations with degraded sediment quality.

There were 125 (41.7%) of the 300 stations (1226.4km^2, 51.9% total study area) with one impaired sediment triad parameter (i.e., intermediate/high quality sediments). They included stations with characteristics similar to those with high quality sediments. The remaining 69 (23%) of the 300 stations (336.8 km^2, 14.3% total study area) displayed two impaired sediment parameters (i.e., intermediate/degraded quality sediments), and in many cases included stations with characteristics similar to those with degraded sediments.

Because of the natural differences in benthic communities among different estuaries, it is difficult to compare the communities from Puget Sound with those from other regions in the U.S. However, benthic data have been generated by the Estuaries component of the Environmental Monitoring and Assessment Program (EMAP) using internally consistent methods. A summary (Long, 2000) of the data from three estuarine provinces (Virginian, Louisianian, Carolinian) showed ranges in results for measures of species richness, total abundance, and a multi-parameter benthic index. The samples with relatively low species richness represented 5%, 4%, and 10% of the survey areas, respectively. Those with relatively low infaunal abundance represented 7%, 19%, and 22% of the areas, respectively. Samples with low benthic index scores represented 23%, 31%, and 20% of the areas. In the Regional EMAP survey of the New York/New Jersey Harbor area, samples classified as having degraded benthos represented 53% of the survey area (Adams et al., 1998). In contrast, it appears that benthic conditions that might be considered degraded occurred much less frequently in Puget Sound than in all of these other areas.

Conclusions

- In the 1999 survey of southern Puget Sound, laboratory tests of 100 samples indicated overlapping, but, different, patterns in toxicity. Based upon analysis of all the data combined, several spatial patterns were apparent in this survey. Most obvious were the toxic responses in the two tests of organic solvents observed in some of the industrialized waterways of Commencement Bay at Tacoma. The responses in the three samples from Thea Foss Waterway were very high in both the HRGS and Microtox™ tests. Significant responses were also observed in both the amphipod and urchin tests in one of the samples. The degree of toxicity in Hylebos and Middle waterways was lower, but, nonetheless, represented conditions considerably different from those reported elsewhere in the survey area. The toxicity observed in the waterways gradually diminished into the outer reaches of the bay and decreased again into East Passage.

- Other industrialized harbors of southern Puget Sound in which sediments induced toxic responses included Port of Olympia, Oakland Bay at Shelton, Gig Harbor, and Port Ludlow. In each case, the toxic responses diminished sharply with increasing distance from these harbors. Sediments in most of the South Sound inlets and passages were relatively homogeneous, i.e., not toxic in any of the tests. However, based upon the HRGS and Microtox™ tests of organic solvents, conditions in the southern Puget Sound inlets and channels were different (i.e., worse) than in the majority of Hood Canal. The patterns of toxicity in the southern Puget Sound, i.e., toxic conditions restricted mainly to industrialized harbors and improving quickly into more rural or undeveloped areas or into the main basin, also were observed in the studies of northern and central Puget Sound.

- The spatial extent of toxicity was estimated by weighting the results of each test to the sizes of the sampling strata. The total study area was estimated to represent about 858 kilometer^2. The area in which highly significant toxicity occurred totaled 0% of the total area in the amphipod survival tests; 5.7% of the area in urchin fertilization tests of 100% pore waters; 0.2% of the area in microbial bioluminescence tests; and 5-38% of the area in the cytochrome P450 HRGS assays. The estimates of the spatial extent of toxicity measured in these tests of southern Puget Sound sediments generally were lower than the "national average" estimates compiled from many other surveys previously conducted by NOAA. Generally, they were comparable to the estimates for northern Puget Sound, but somewhat higher than what was observed in the central region. In the cytochrome P450 HRGS assays, a relatively high proportion of samples caused moderate responses. These data suggest that southern Puget Sound sediments were not unusually toxic relative to sediments from other areas. The large majority of the area surveyed was classified as non-toxic in these tests. However, the data from the HRGS assays indicated a slight to moderate response among many samples.

- Twenty of the 100 samples collected had one or more chemical concentrations that exceeded applicable NOAA guidelines and/or Washington state criteria. Among these samples, chemical contamination was highest in eight samples collected in or near the industrialized waterways of Commencement Bay. Samples from the Thea Foss and Middle Waterways were primarily contaminated with a mixture of PAHs and trace metals, whereas those from Hylebos Waterway were contaminated with chlorinated organic hydrocarbons. The remaining 12 samples with elevated chemical concentrations primarily had high levels of other chemicals, including bis(2-ethylhexyl) phthalate, benzoic acid, benzyl alcohol, and phenol. There was a distinct spatial pattern in contamination in Commencement Bay (i.e., high concentrations in the waterways diminished rapidly into the outer reaches of the bay). However, there were no other equally clear gradients elsewhere in the study area.

- For all trace metals (excluding nickel), there were a total of 4 (ERM), 3 (SQS), and 3 (CSL) samples exceeding guidelines or criteria levels, encompassing a total of 0.84, 0.68, and 0.68%, respectively, of the total study area. Significant metals contamination occurred in Port Gamble Bay, Totten Inlet, and in both the Thea Foss and Middle Waterways of Commencement Bay, and mercury was the most commonly found contaminant. There were a total of 6, 4, and 1 samples with PAHs exceeding ERM, SQS, and CSL values, respectively, encompassing a total of 0.30, 0.23, and <0.01% of the total study area. Contaminants were again located in Port Gamble Bay and Commencement Bay, including both the Thea Foss and Middle Waterways. PCB chemicals exceeded guidelines and criteria in 2 (ERM) and 3 (SQS) stations in the Thea Foss and Hylebos Waterways, representing 0.04 and 0.07% of the study area. Other organic chemicals, including benzoic acid, benzyl alcohol exceeded SQS and CSL values in 5 or fewer samples, representing roughly 3% or less of the study area, including stations in Budd Inlet, Port of Olympia, Henderson Inlet, E. Anderson Island, and Hale and Pickering Passages. Hexachlorobenzene values exceeded the SQS value at all three stations in the Hylebos Waterway (0.08% of the study area).

- The highest chemical concentrations invariably were observed in samples collected in the urbanized bays, namely the waterways adjoining Commencement Bay. Slight degrees of contamination also were apparent in some samples from Port Ludlow, Port Gamble Bay, Port of Olympia, Shelton Harbor, and Gig Harbor. Areas with lowest chemical concentrations included most of Hood Canal and many of the southern Puget Sound inlets and passages.

- Toxicity tests performed for urchin fertilization, microbial bioluminescence, and cytochrome HRGS enzyme induction indicated correspondence with complex mixtures of potentially toxic chemicals in the sediments. Often, the results of the Microtox™ and cytochrome P450 HRGS tests showed the strongest correlations with chemical concentrations. Whereas the urchin fertilization tests showed correlations with chemical concentrations in northern and central Puget Sound, they failed to indicate such patterns in southern Puget Sound. As expected, given the nature of the tests, results of the cytochrome P450 HRGS assay were highly correlated with concentrations of high molecular weight PAHs and other organic chemicals known to induce this enzymatic response. In some cases, samples that were highly toxic in the cytochrome P450 HRGS tests had chemical concentrations that exceeded numerical, effects-based, sediment quality guidelines or criteria, further suggesting that these chemicals could have caused or contributed to the observed biological response. The relationships between the HRGS response and concentrations of PAHs were also observed in central and northern Puget Sound.

- As with the previous infaunal assemblage studies conducted in north and central Puget Sound (Long, et al. 1999a, 2000), benthic infaunal assemblages in south Puget Sound display a wide variety of characteristics in different locations and habitat types throughout the study area. Infaunal assemblages examined typically displayed relatively high abundance, taxa richness, evenness, and dominance values. Polychaetes were typically the most abundant taxa group (up to 93% of the infaunal composition), followed by arthropods (up to 75%), mollusks (up to 70%), echinoderms (up to 55%), and miscellaneous taxa (up to 33%). Two samples collected in the Port of Olympia near a superfund cleanup site had no living organisms in them.

- In general, many of the small embayments and inlets throughout the study area had infaunal assemblages with relatively low total abundance, taxa richness, evenness, and dominance values. In some of the small urban/industrial embayments however, cases were found where total abundance values were very high, typically due to high abundance of one organism such as the polychaete *Aphelochaeta* sp. N1; the mollusk *Axinopsida serricata*; the arthropod *Aoroides spinosus*; or the echinoderm *Amphiodia urtica/periercta* complex. The majority of the samples collected from passages, outer embayments, and larger bodies of water tended to possess infaunal assemblages with higher total abundance, taxa richness, evenness, and dominance values.

- Statistical analyses of the toxicity data and benthic data revealed few consistent patterns. Results of the Microtox™ tests and HRGS assays, on the other hand, showed strong correlations with indices of evenness and dominance that were highly significant. As Microtox™ bioluminescence EC50 values decreased (indicating increasing toxicity), the evenness index and the numbers of dominant species also decreased. As HRGS induction increased (indicative of exposure of toxicants), the indices of evenness and dominance decreased.

- The relationships between measures of benthic structure and chemical concentrations showed mixed results. Both taxa richness and the dominance index were negatively correlated with the concentrations of trace metals in the samples. Total abundance and taxa richness were highly correlated with the concentrations of PAHs in the samples. However, these correlations were positive, indicating that the abundance of the benthos and the numbers of species increased as the concentrations of PAHs increased. In addition, the abundance of annelids and molluscs showed increasing abundance with increasing PAH concentrations. The data suggest that the benthos was tolerant of the chemical concentrations in these samples and attracted to the sampled areas by other ecological factors, such as high organic matter.

- A weight-of-evidence approach, used to simultaneously examine all three "sediment triad" parameters measured and define each station based on the number of impaired parameters measured at the station, generated four categories of sediment quality, including "high quality" (none of the sediment triad parameters impaired), "intermediate/high quality" (one sediment triad parameter impaired), "intermediate/degraded quality" (two sediment triad parameters impaired), and "degraded quality" (all of the sediment triad parameters impaired).

- There were 11 stations (4.4 km^2, 0.5% total study area) with sediment toxicity, chemical contamination, and altered benthos (i.e., "degraded sediment quality"). Typically, these stations were shallow, represented a small area, were primarily located in major urban areas, and had relatively fine grain size and high TOC values. Infaunal assemblages typically had higher total abundance (usually due to one or two abundant dominant organisms), moderate taxa richness and evenness, lower dominance values, and were dominated by annelids (sometimes in high abundance), followed by molluscs, arthropods, echinoderms, and miscellaneous taxa. The polychaete species *Aphelochaeta* sp. N1 was the dominant taxa at ten of the eleven stations.

- In contrast, 36 stations (493.5 km^2, 57.5% total study area) displayed no toxicity or chemical contamination, and supporting abundant and diverse infaunal assemblages. These stations typically included the larger, deeper inlets, basins, and passages of the more rural areas of south Puget Sound and Hood Canal, as well as a few smaller embayments. They tended to have coarser sediment with lower TOC content than those stations with degraded sediment quality. Infaunal assemblages at these stations had lower total abundance, and higher evenness and dominance values than those stations with degraded sediment quality.

- Thirty-five stations (274.1 km^2, 32.0% total study area) had one impaired sediment triad parameter (i.e., intermediate/high quality sediments), and included stations with characteristics similar to those with high quality sediments. The remaining 18 stations (85.7km^2, 10.0% total study area) displayed two impaired sediment parameters (i.e., intermediate/degraded quality sediments), and included stations with characteristics similar to those with degraded sediments.

- The number of stations displaying degraded sediments based upon the sediment quality triad of data was slightly greater in the central Puget Sound than in the northern and southern Puget Sound study areas, with the percent of the total study area degraded in each region decreasing from central to north to south (2.8, 1.3 and 0.5%, respectively). In comparison with data from other marine bays and estuaries surveyed by NOAA using the same methods, sediments in Puget Sound were among the least contaminated and toxic.

- Data from these surveys of Puget Sound sediment quality provide the basis for quantifying changes in sediment quality, if any, in future years. A stratified-random sampling design will be used along with similar suite of analytical methods in future surveys to generate comparable data, allowing the state of Washington to measure changes in sediment quality in terms of the percentage of the area that is degraded.

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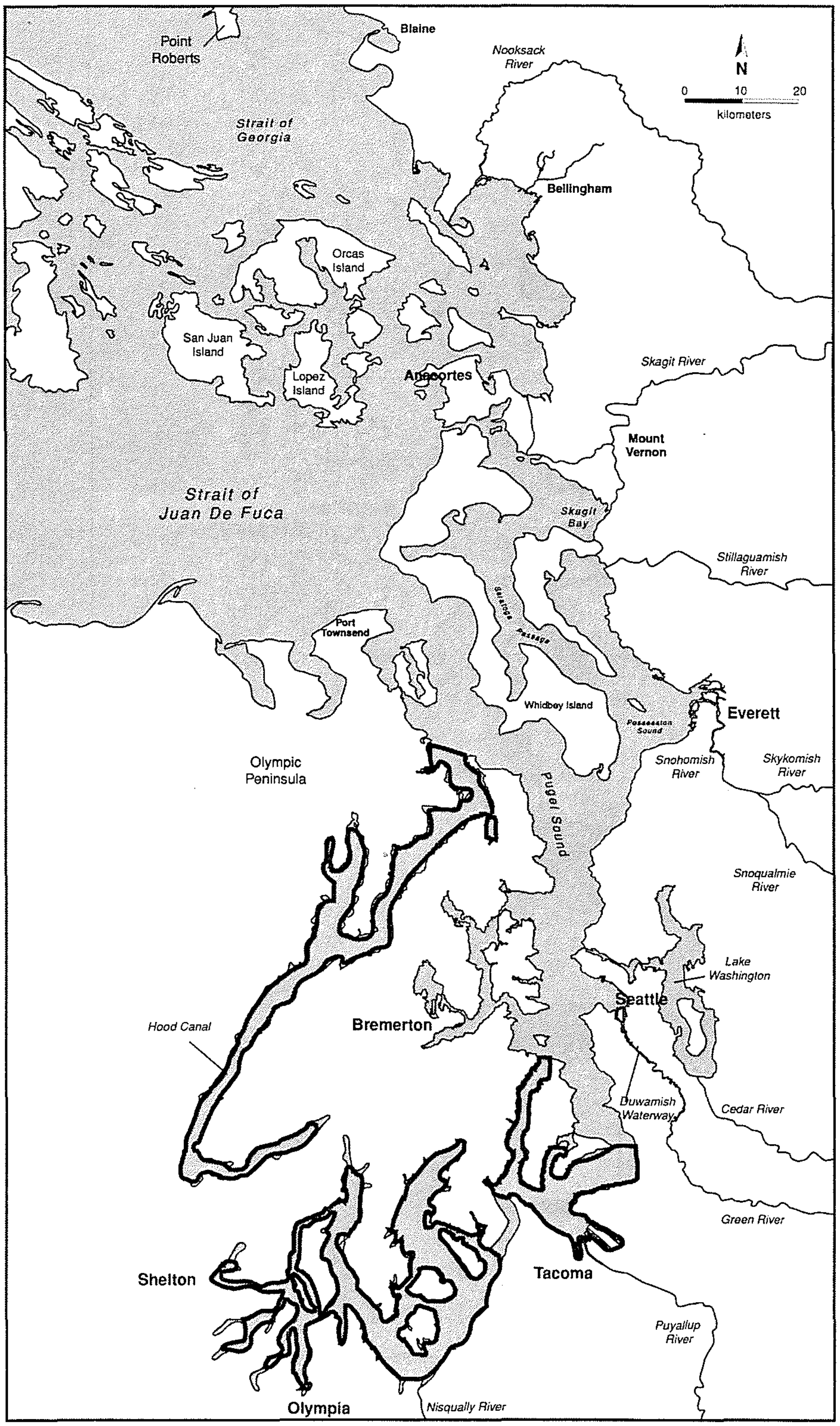


Figure 1. Map of the southern Puget Sound study area for the NOAA/PSAMP Bioeffects Survey. The areas sampled during 1999 are outlined.

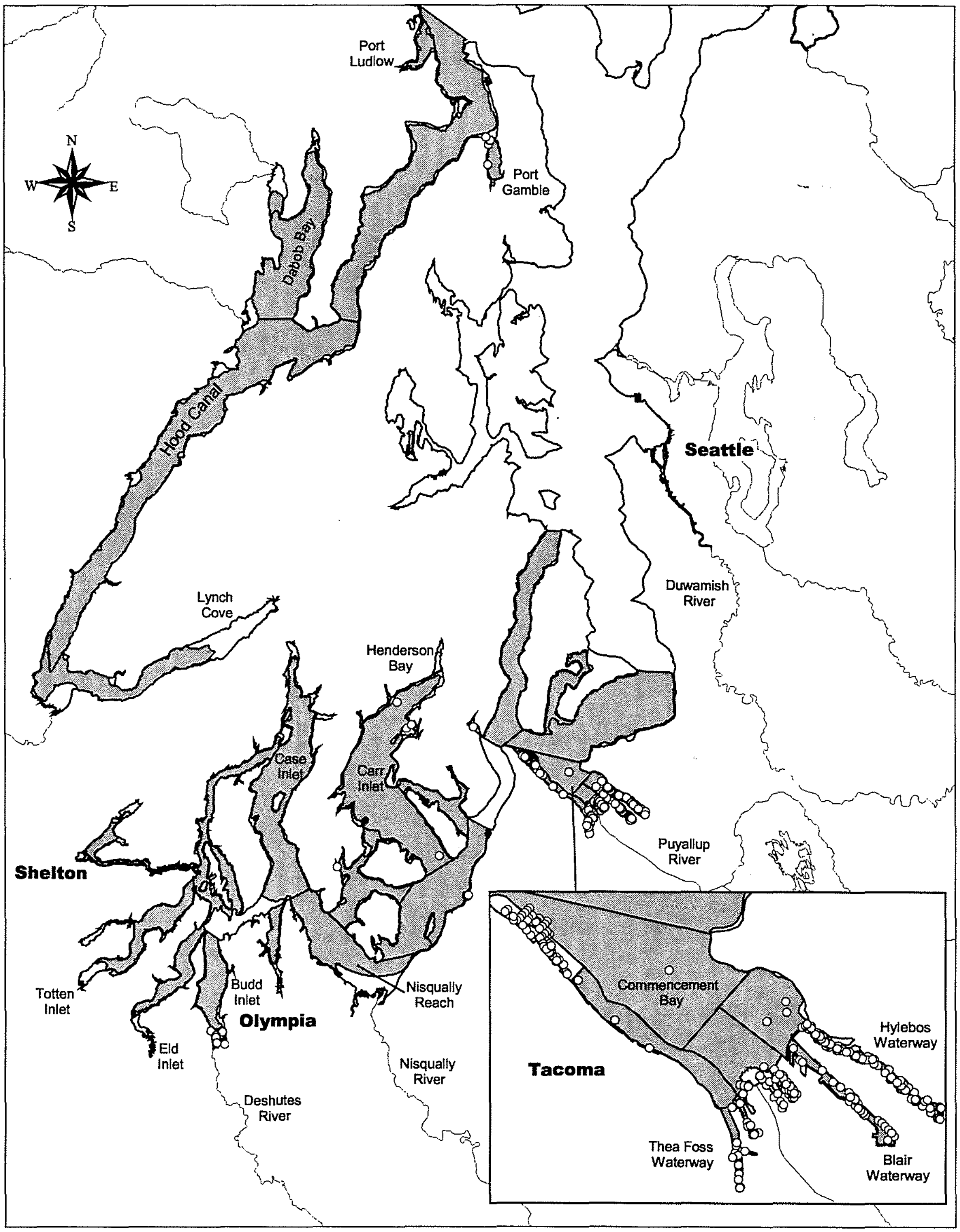


Figure 2. Map of 1999 southern Puget Sound survey area, SEDQUAL stations where chemical contaminants in sediment samples exceeded Washington State Sediment Quality Standards (SQS) and Puget Sound Marine Sediment Cleanup Screening Levels (CSL).

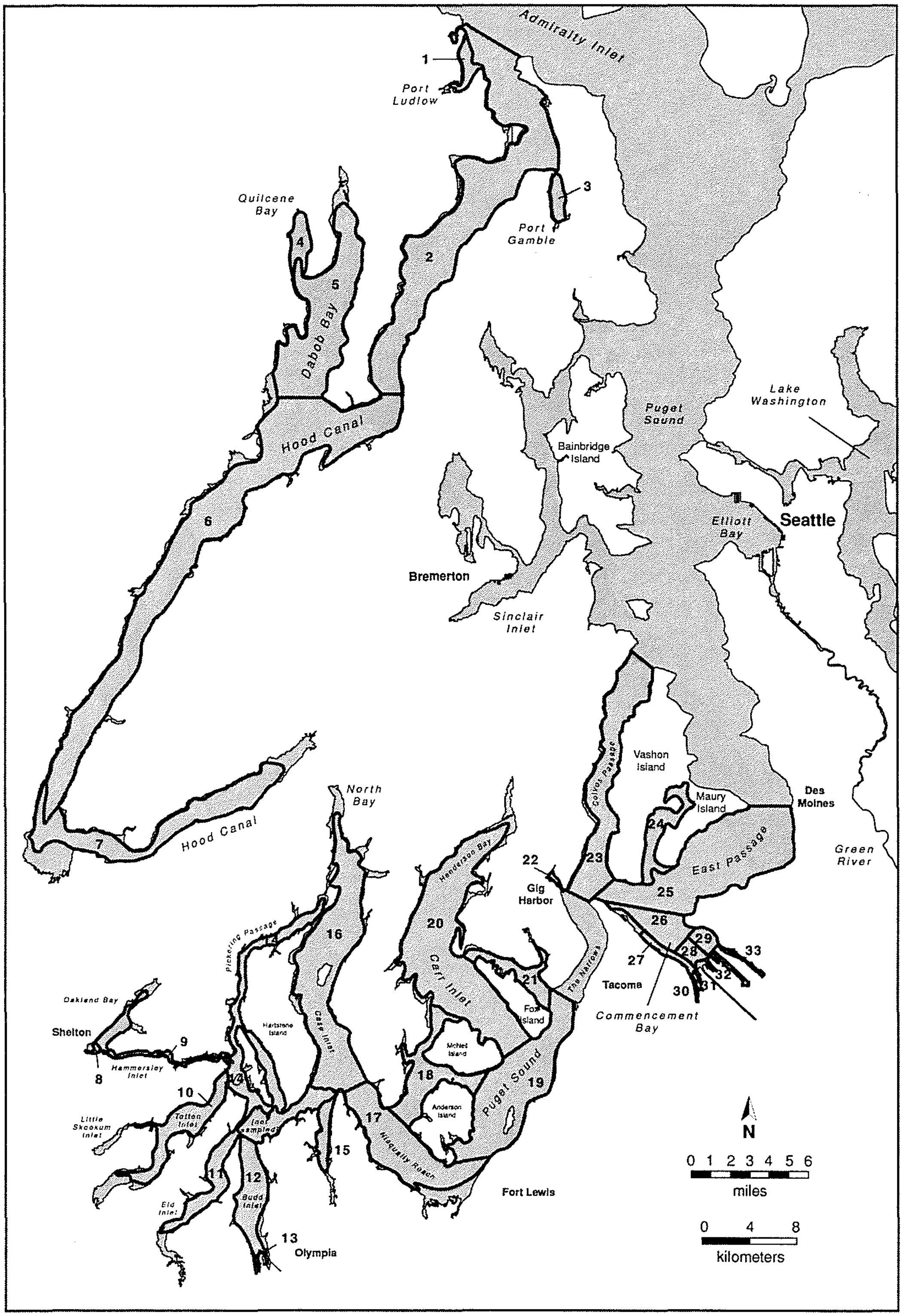


Figure 3a. Southern Puget Sound sampling strata for the PSAMP/NOAA Bioeffects Survey, all strata.

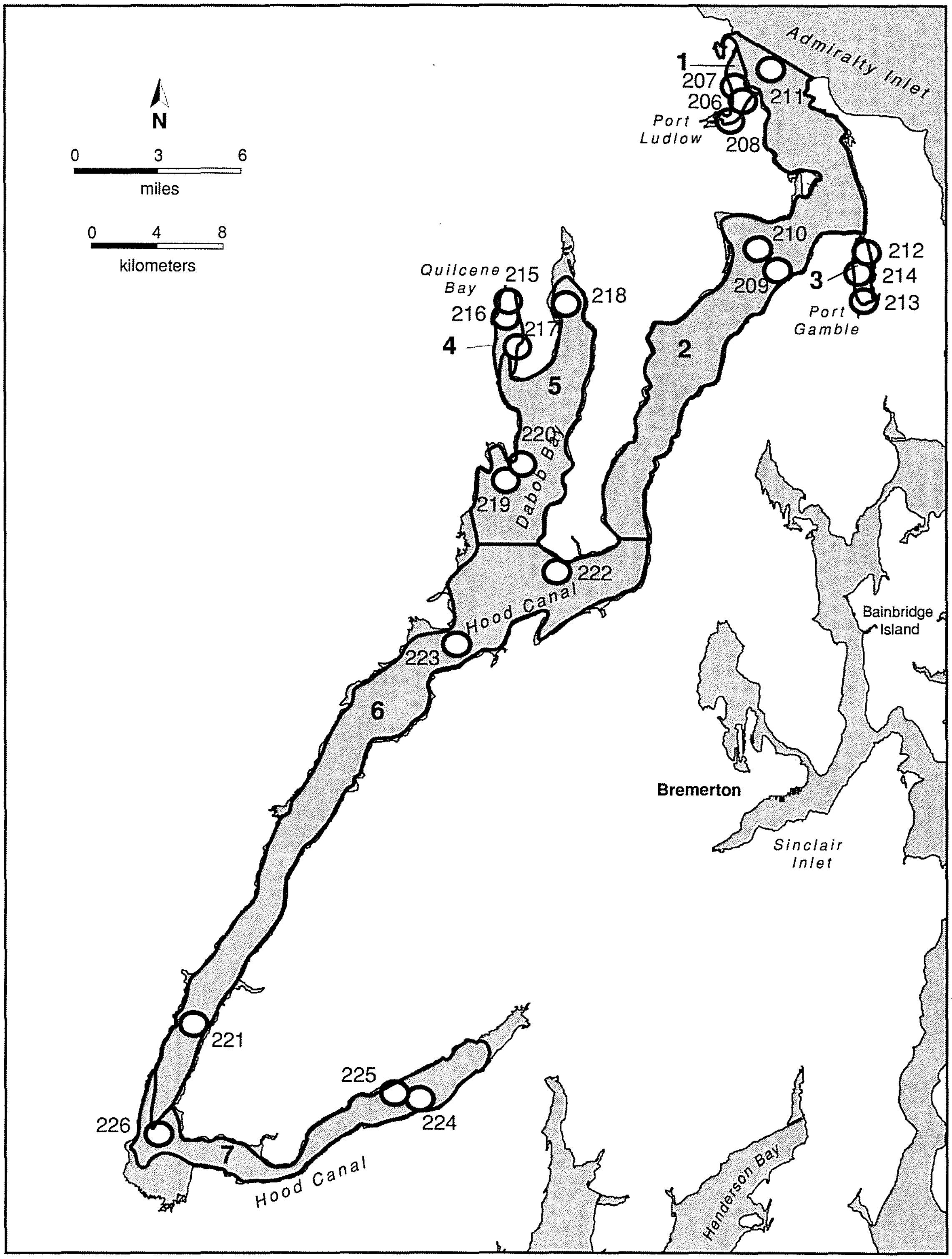


Figure 3b. Southern Puget Sound sampling stations for the 1999 PSAMP/NOAA Bioeffects Survey, Admiralty Inlet through Hood Canal (strata 1 through 7). (Strata numbers are shown in bold. Stations are identified as sample number).

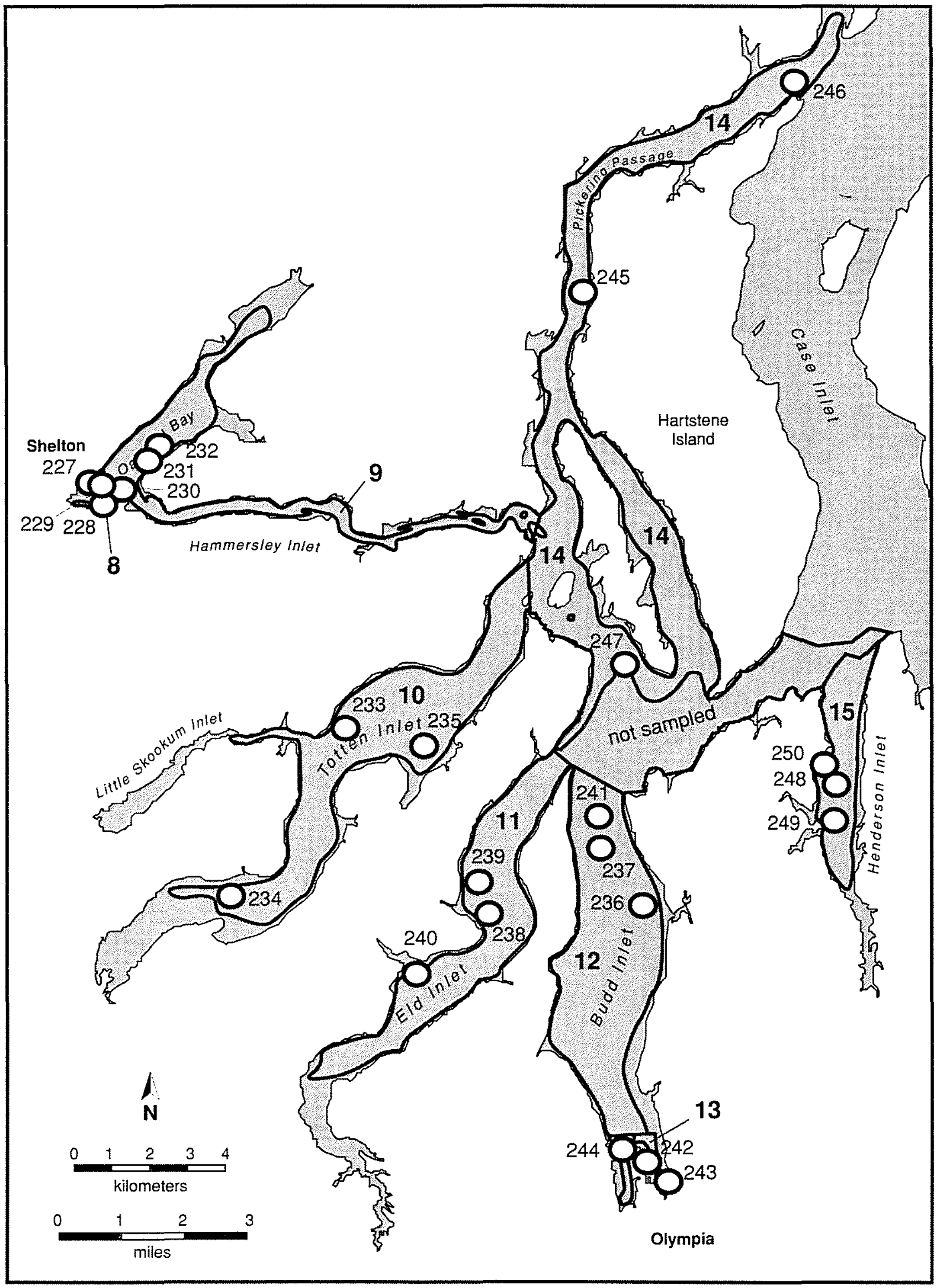


Figure 3c. Southern Puget Sound sampling stations for the 1999 PSAMP/NOAA Bioeffects Survey, Pickering Passage through Henderson Inlet (8 through 15). (Strata numbers are shown in bold. Stations are identified as sample number).

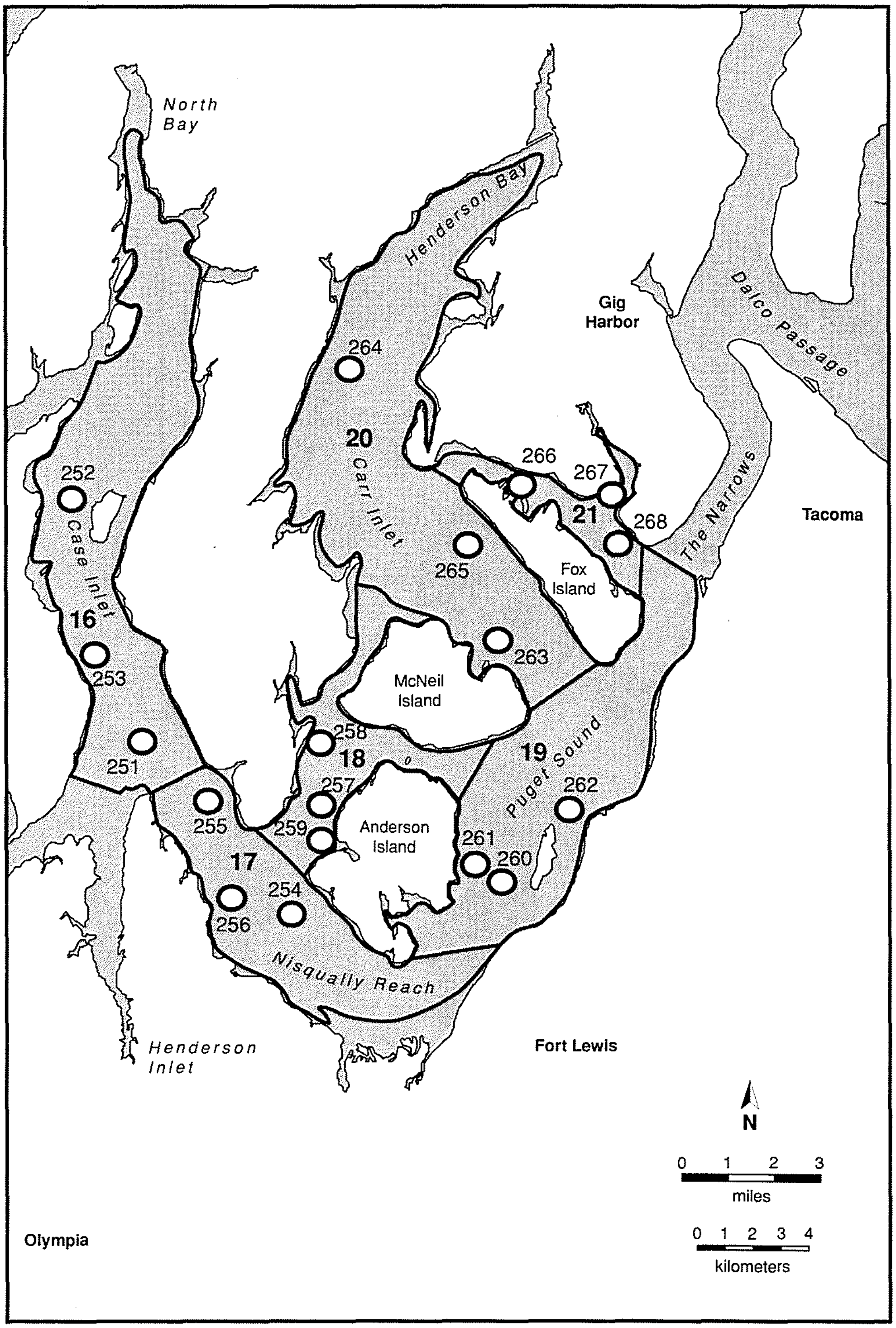


Figure 3d. Southern Puget Sound sampling stations for the 1999 PSAMP/NOAA Bioeffects Survey, Case Inlet, Carr Inlet, and vicinity of Anderson and Fox Island (strata 16 through 21). (Strata numbers are shown in bold. Stations are identified as sample number).

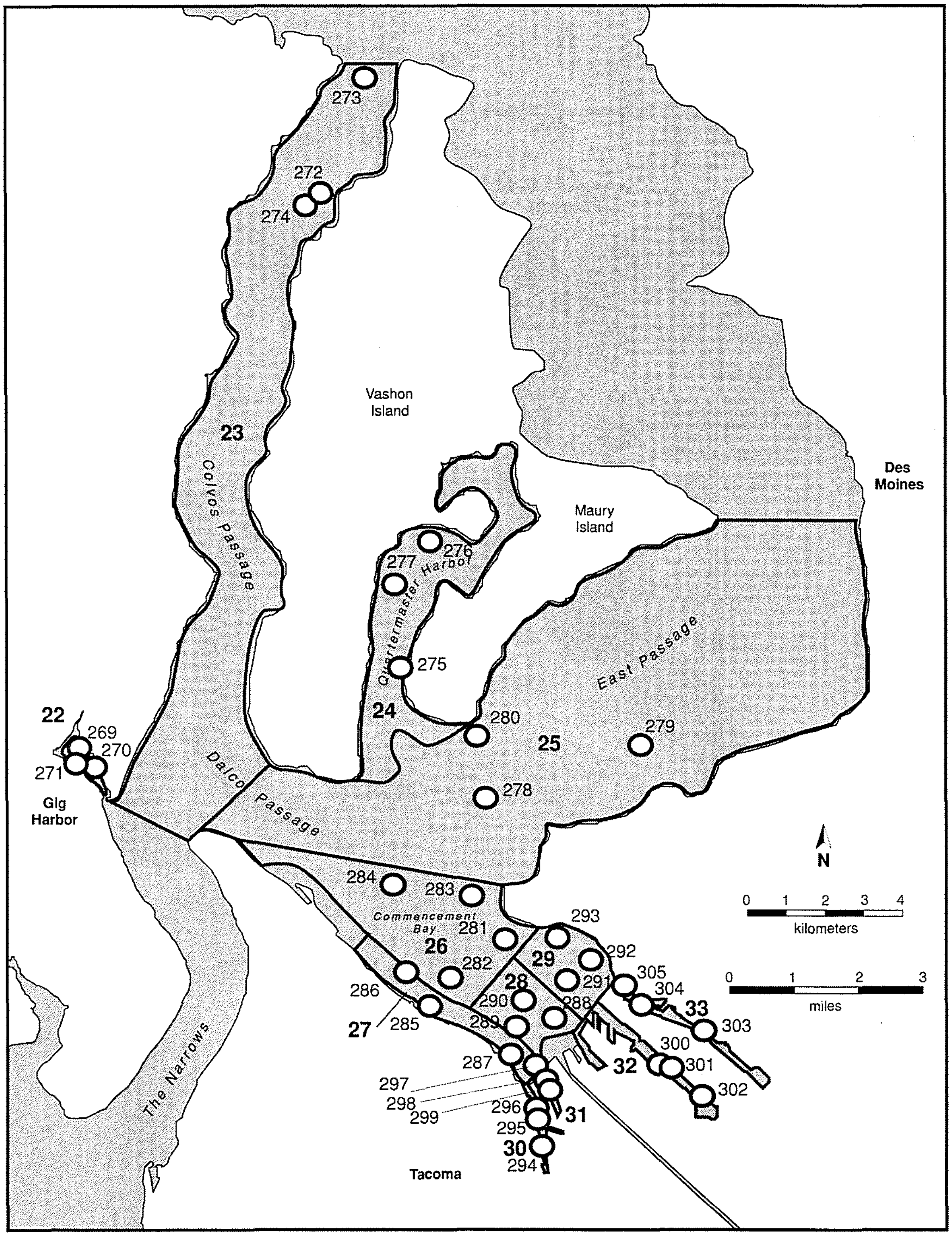


Figure 3e. Southern Puget Sound sampling stations for the 1999 PSAMP/NOAA Bioeffects Survey, Colvos Passage, Gig Harbor, Quartermaster Harbor, East Passage, and Commencement Bay (strata 22 through 33). (Strata numbers are shown in bold. Stations are identified as sample number).

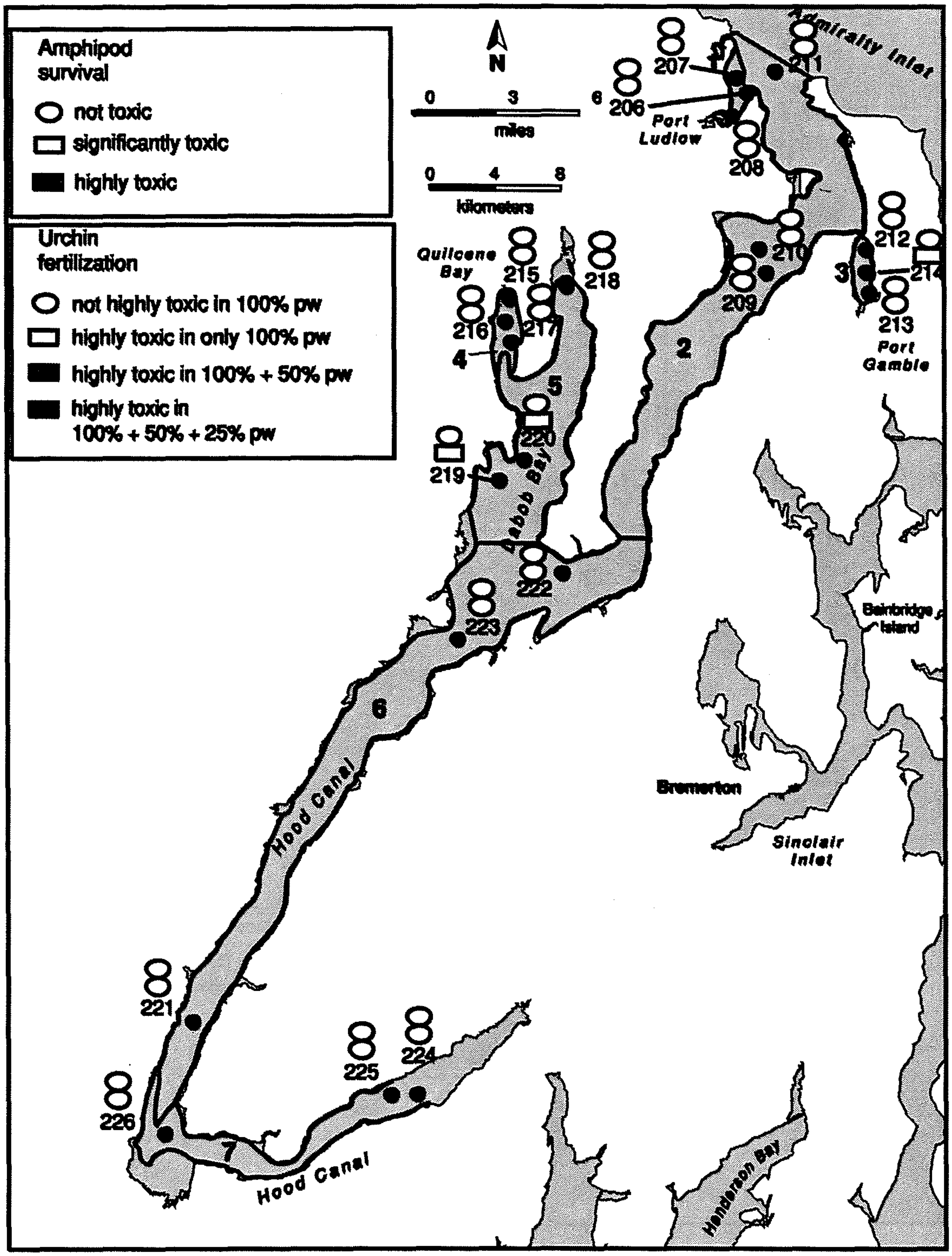


Figure 4. Summary of 1999 amphipod survival tests (top symbols) and sea urchin fertilization tests (in three porewater concentrations, bottom symbols) for stations in Admiralty Inlet through Hood Canal (strata 1 through 7). (Strata numbers are shown in bold. Stations are identified as sample number).

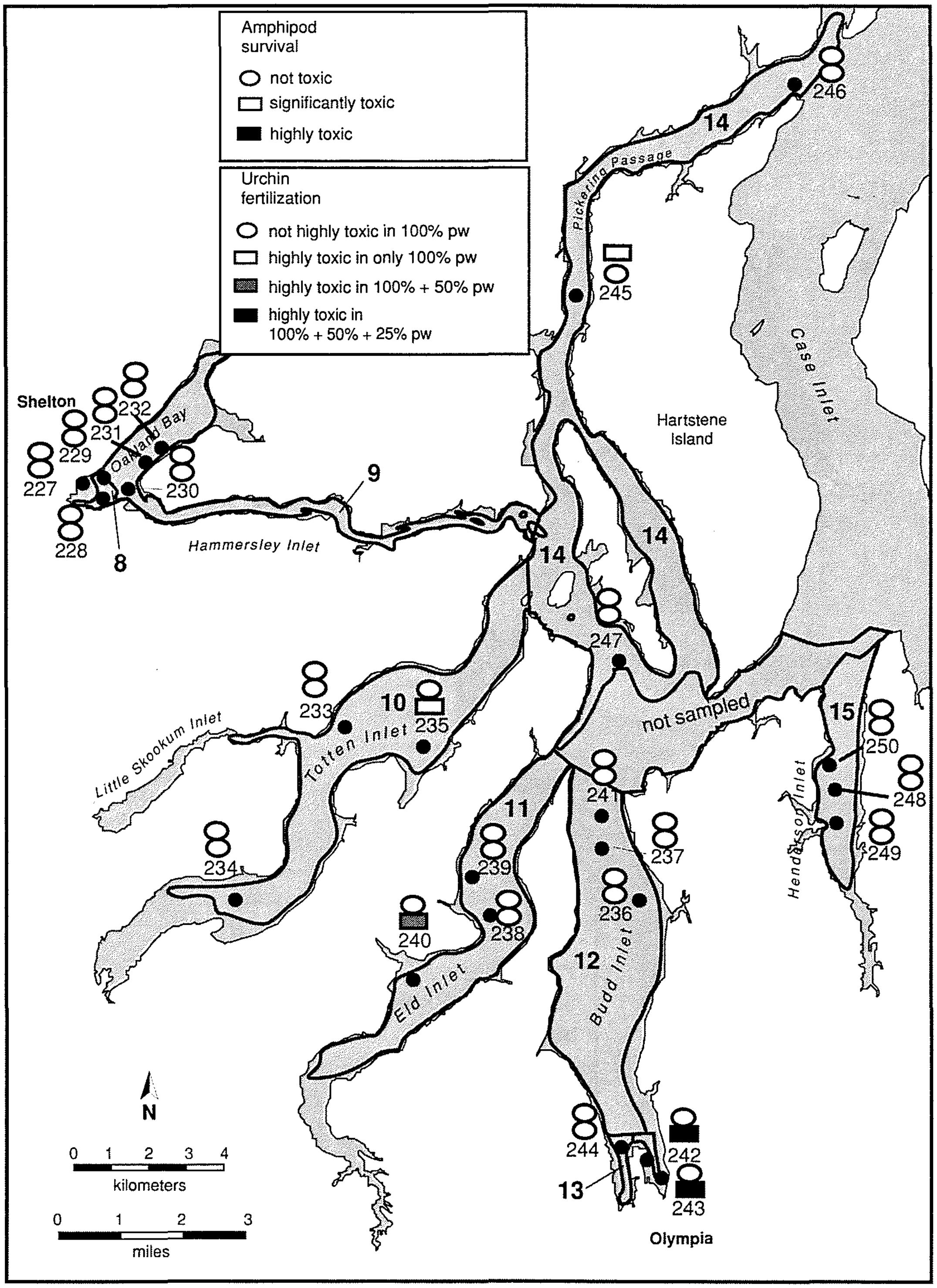


Figure 5. Summary of 1999 amphipod survival tests (top symbols) and sea urchin fertilization tests (in three porewater concentrations, bottom symbols) for stations in Pickering Passage through Henderson Inlet (8 through 15). (Strata numbers are shown in bold. Stations are identified as sample number).

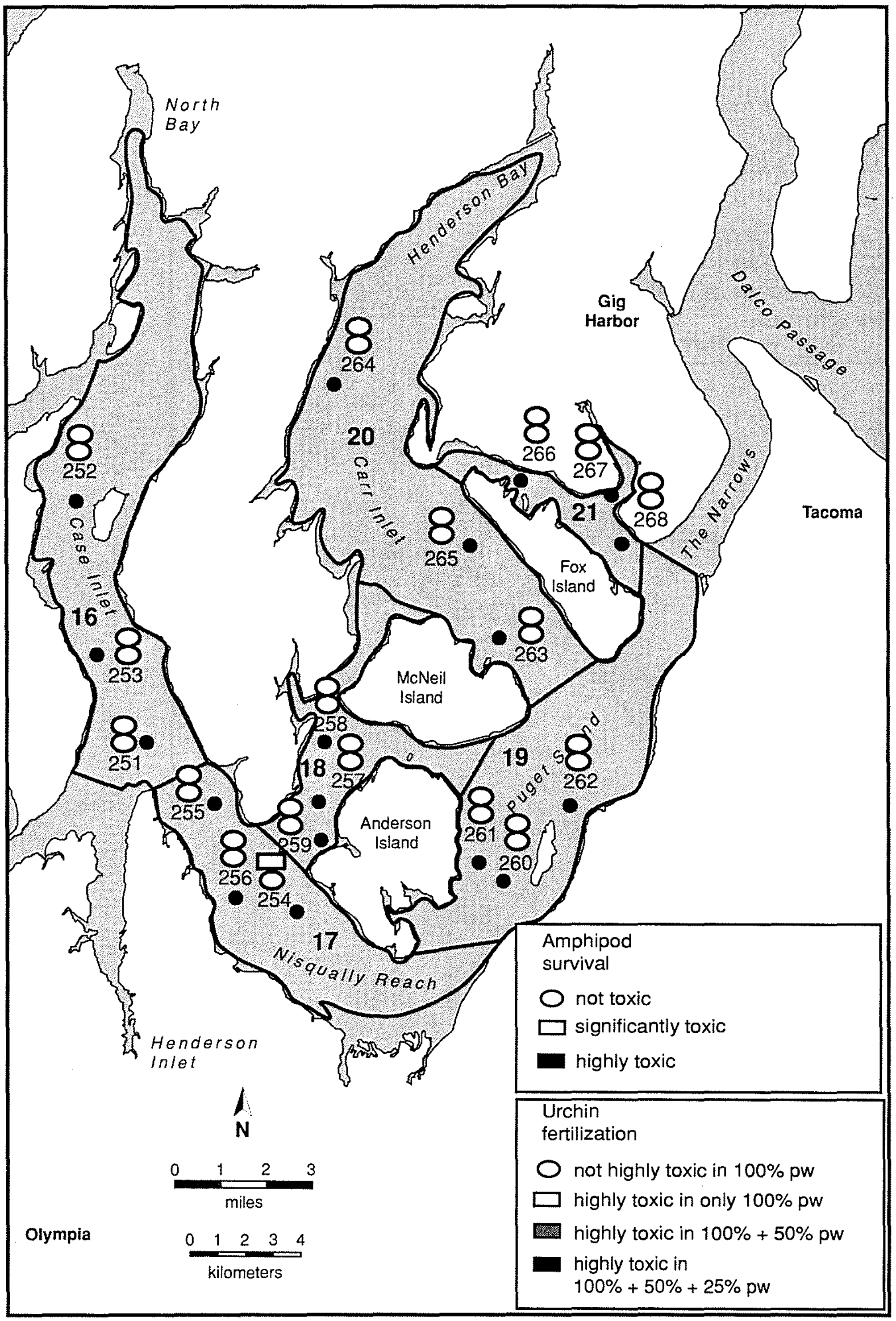


Figure 6. Summary of 1999 amphipod survival tests (top symbols) and sea urchin fertilization tests (in three porewater concentrations, bottom symbols) for stations in Case Inlet, Carr Inlet, and vicinity of Anderson and Fox Island (strata 16 through 21). (Strata numbers are shown in bold. Stations are identified as sample number).

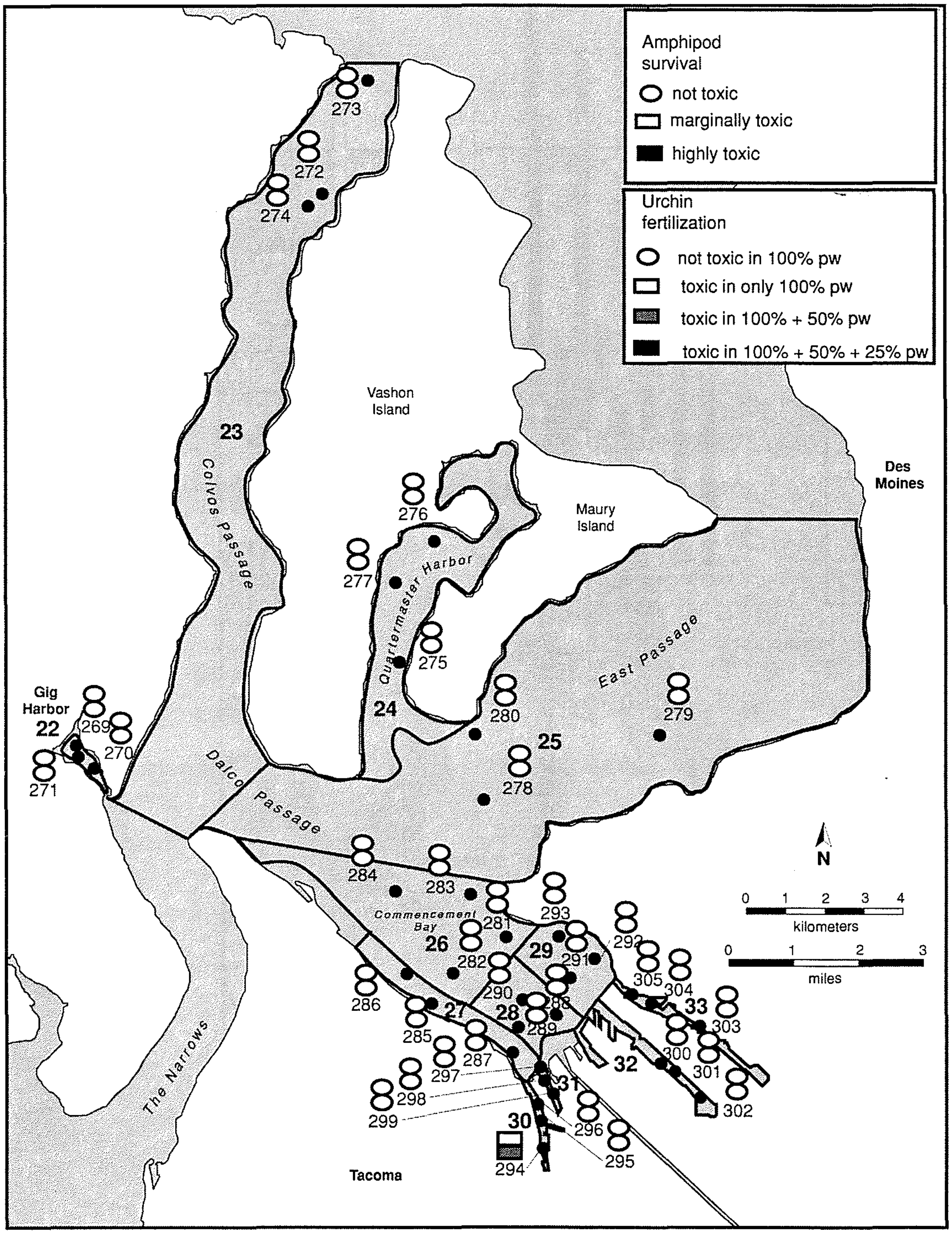


Figure 7. Summary of 1999 amphipod survival tests (top symbols) and sea urchin fertilization tests (in three porewater concentrations, bottom symbols) for stations in Colvos Passage, Gig Harbor, Quartermaster Harbor, East Passage, and Commencement Bay (strata 22 through 33). (Strata numbers are shown in bold. Stations are identified as sample number).

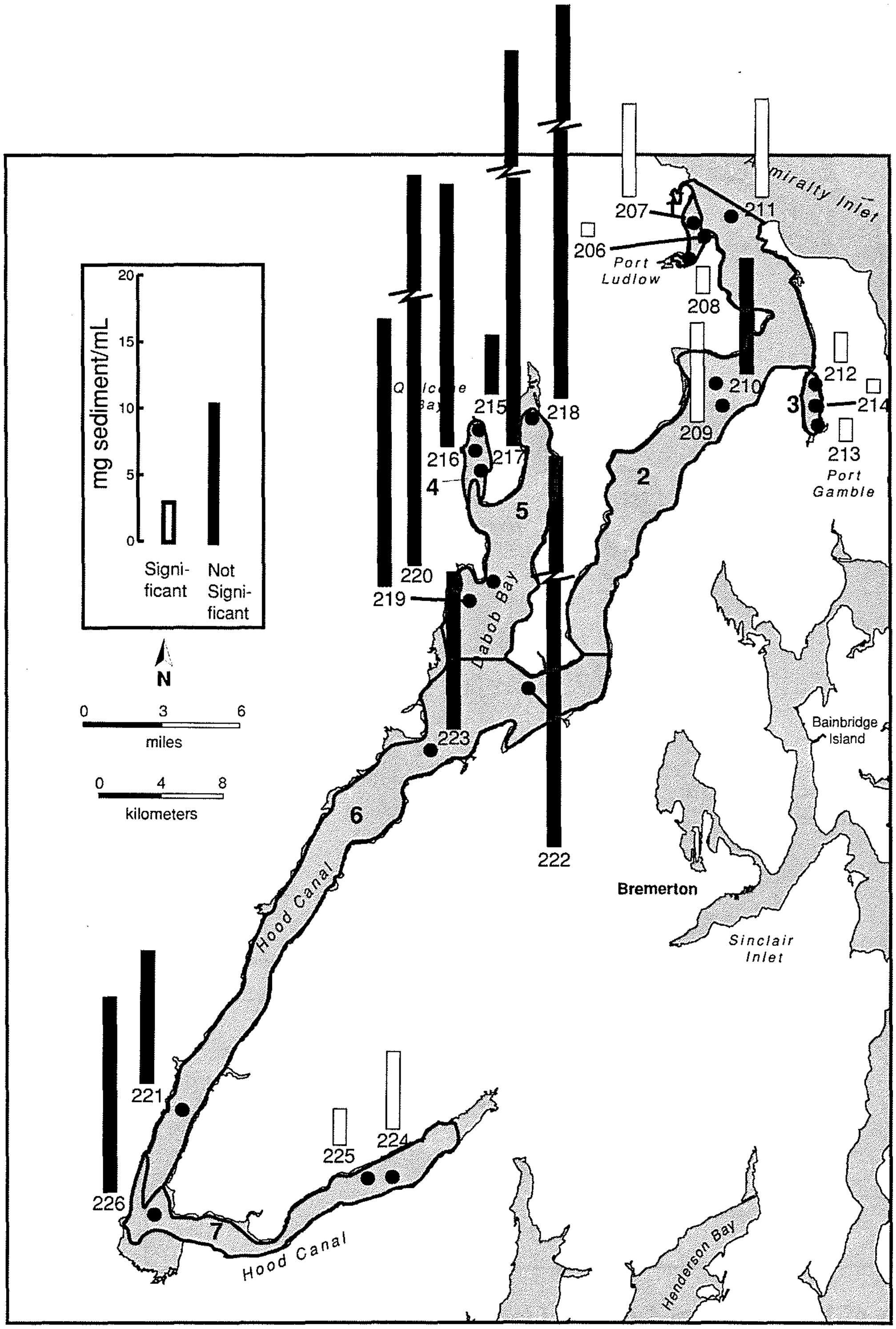


Figure 8. Results of 1999 Microtox™ bioluminescence tests for stations in Admiralty Inlet through Hood Canal (strata 1 through 7). (Strata numbers are shown in bold. Stations are identified as sample number).

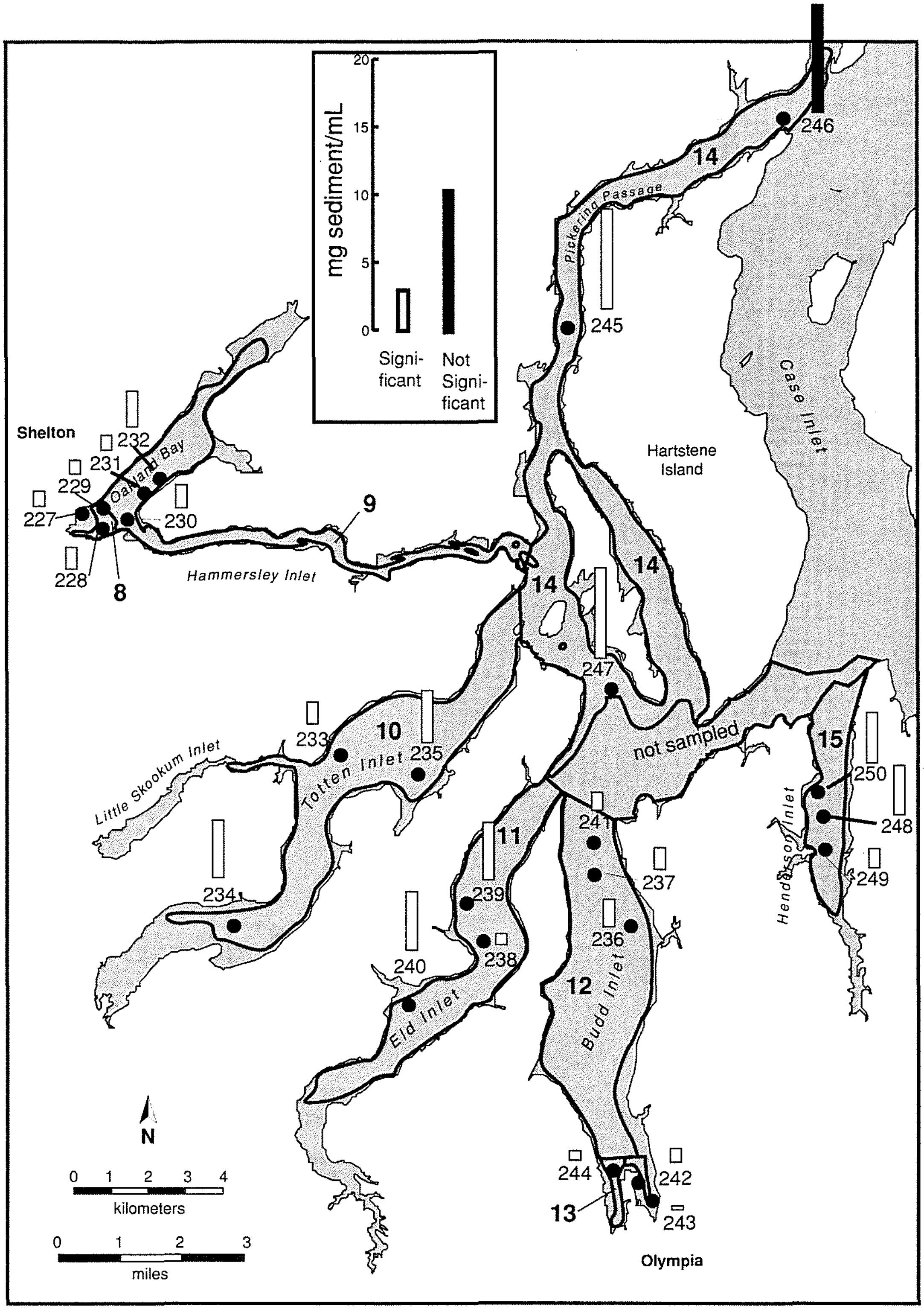


Figure 9. Results of 1999 Microtox™ bioluminescence tests for stations in Pickering Passage through Henderson Inlet (8 through 15). (Strata numbers are shown in bold. Stations are identified as sample number).

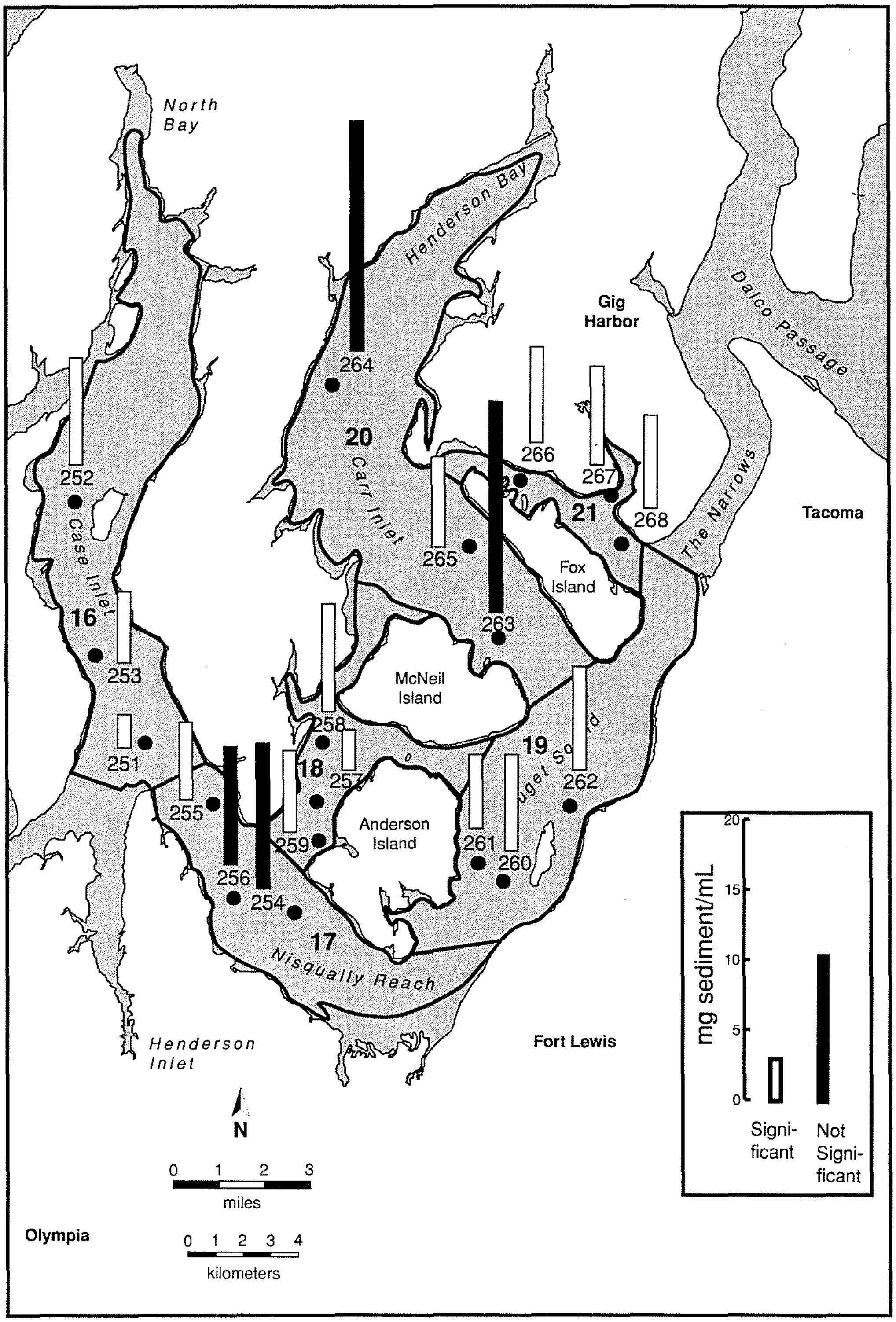


Figure 10. Results of 1999 Microtox™ bioluminescence tests for stations in Case Inlet, Carr Inlet, and vicinity of Anderson and Fox Island (strata 16 through 21). (Strata numbers are shown in bold. Stations are identified as sample number).

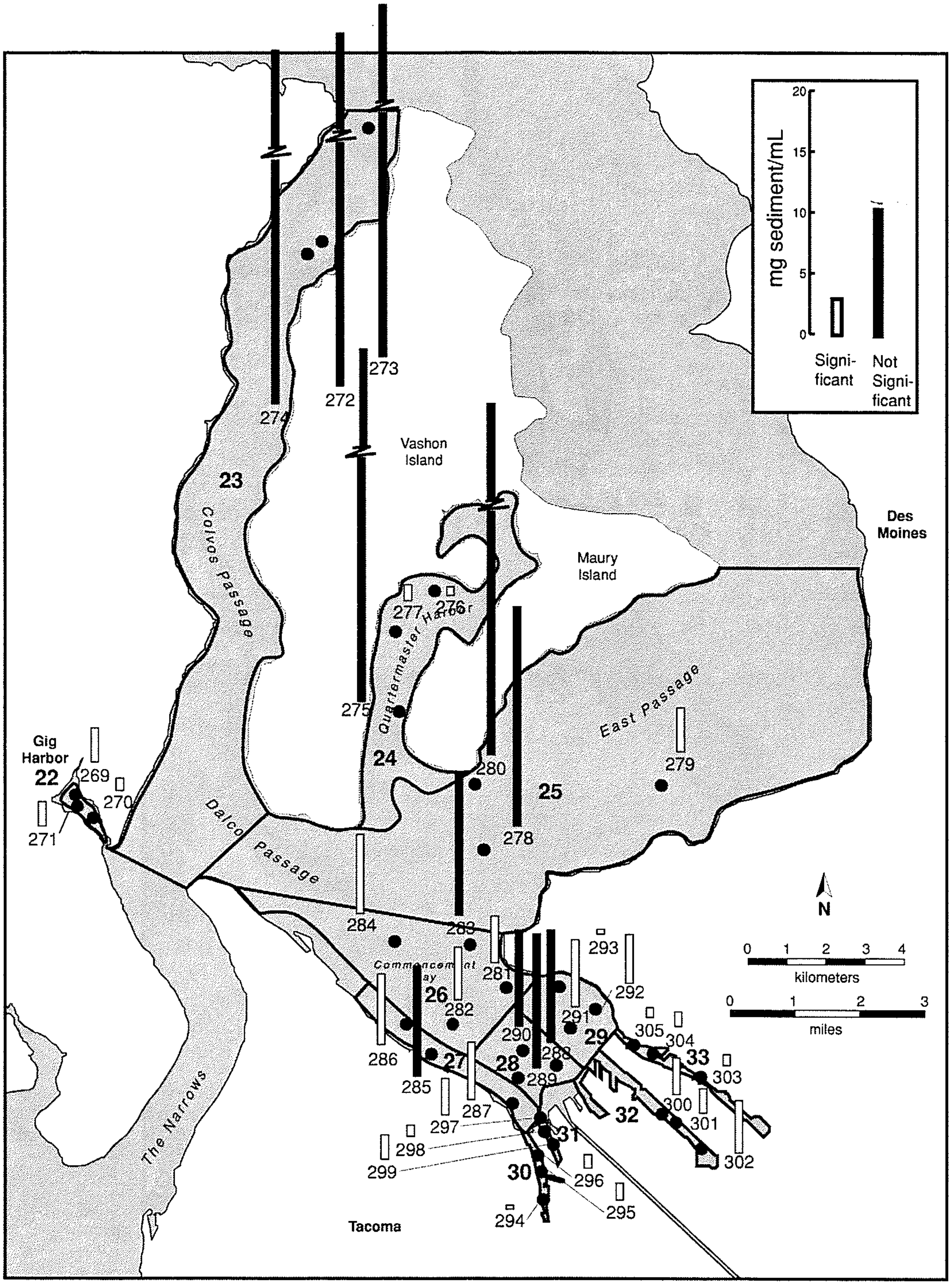


Figure 11. Results of 1999 Microtox™ bioluminescence for stations in Colvos Passage, Gig Harbor, Quartermaster Harbor, East Passage, and Commencement Bay (strata 22 through 33). (Strata numbers are shown in bold. Stations are identified as sample number).

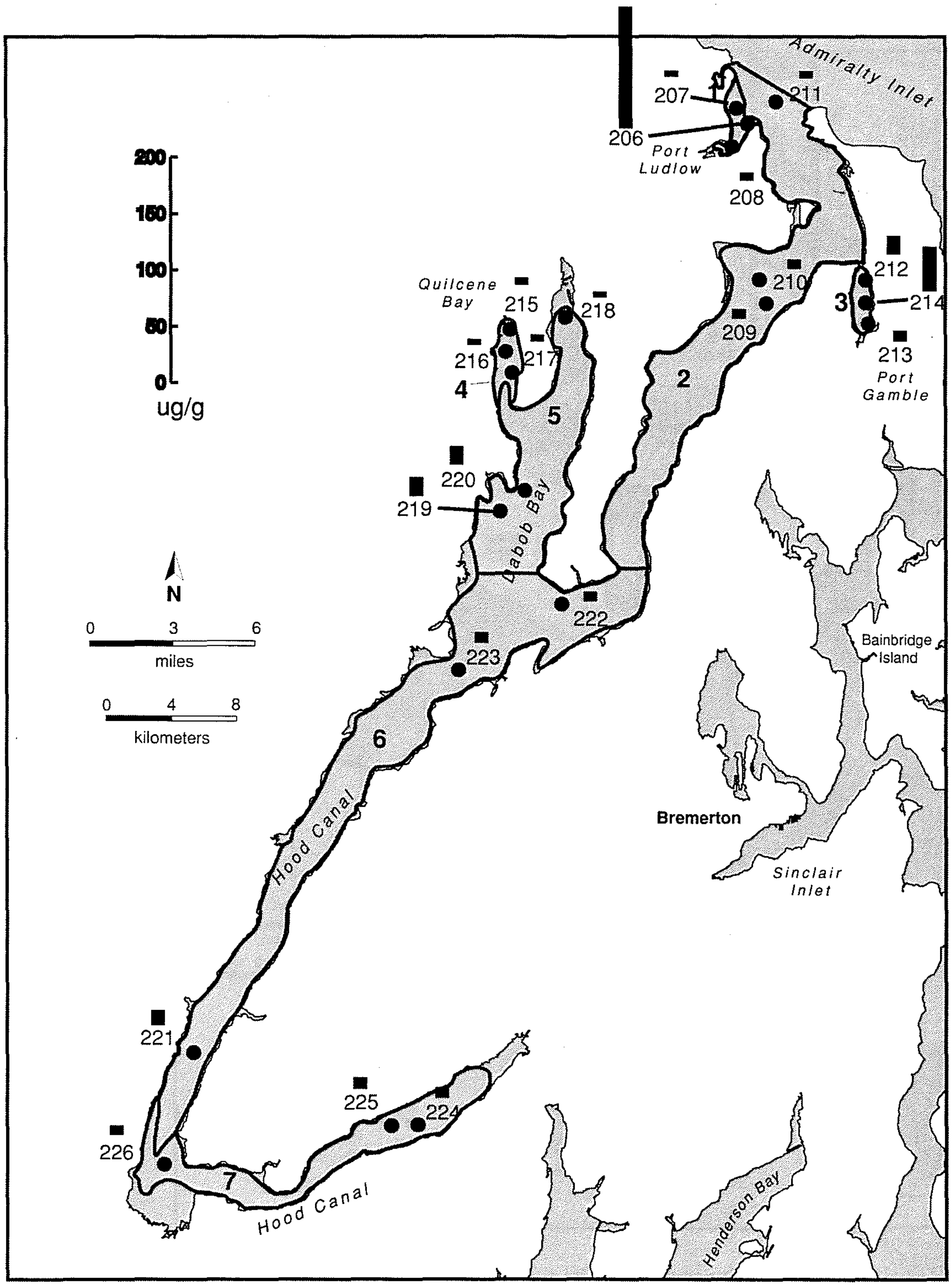


Figure 12. Results of 1999 cytochrome P450 HRGS assays (as B[a]P equivalents (μg /g)) for stations in Admiralty Inlet through Hood Canal (strata 1 through 7). (Strata numbers are shown in bold. Stations are identified as sample number).

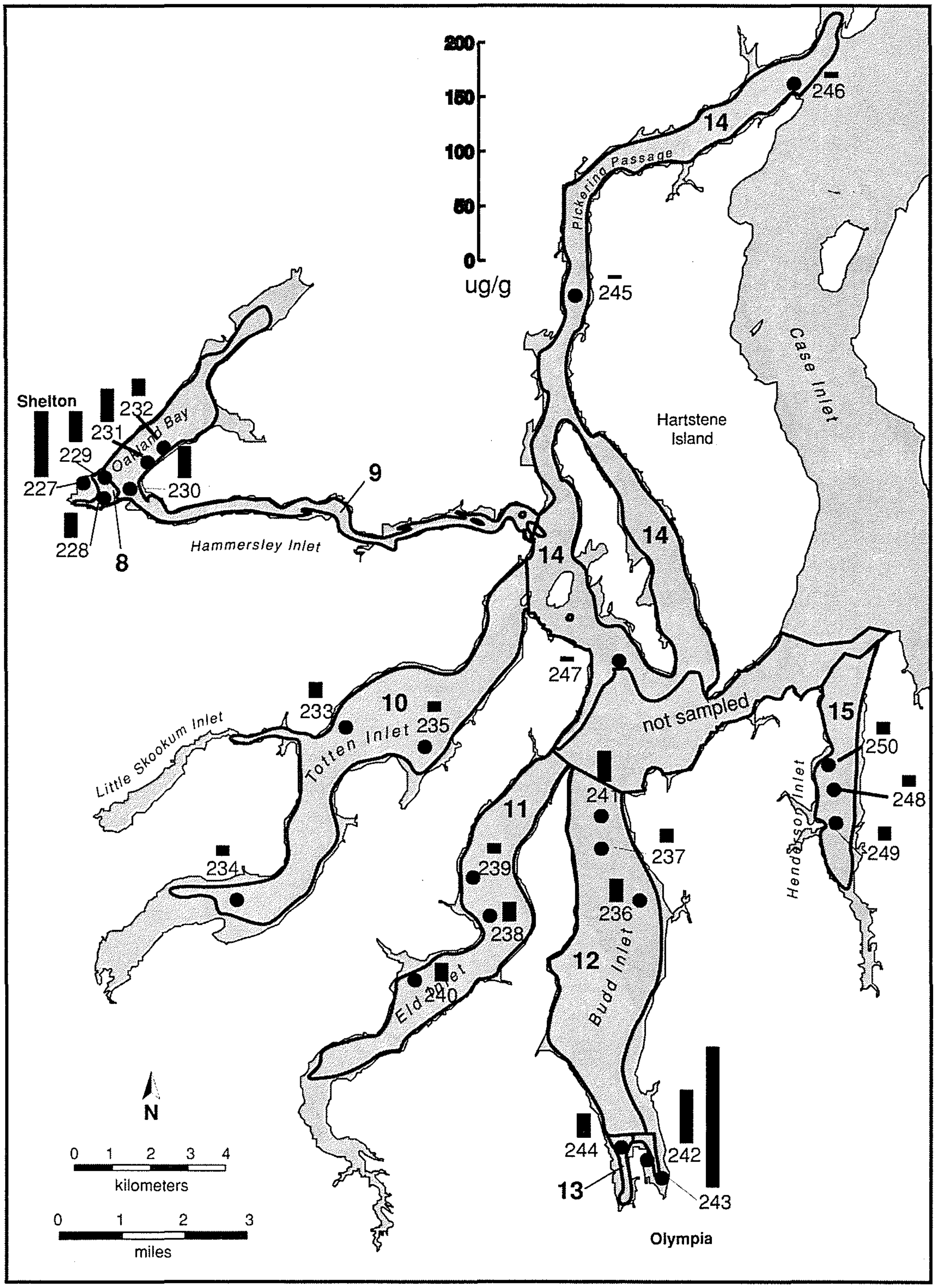


Figure 13. Results of 1999 cytochrome P450 HRGS assays (as B[a]P equivalents (μg /g)) for stations in Pickering Passage through Henderson Inlet (8 through 15). (Strata numbers are shown in bold. Stations are identified as sample number).

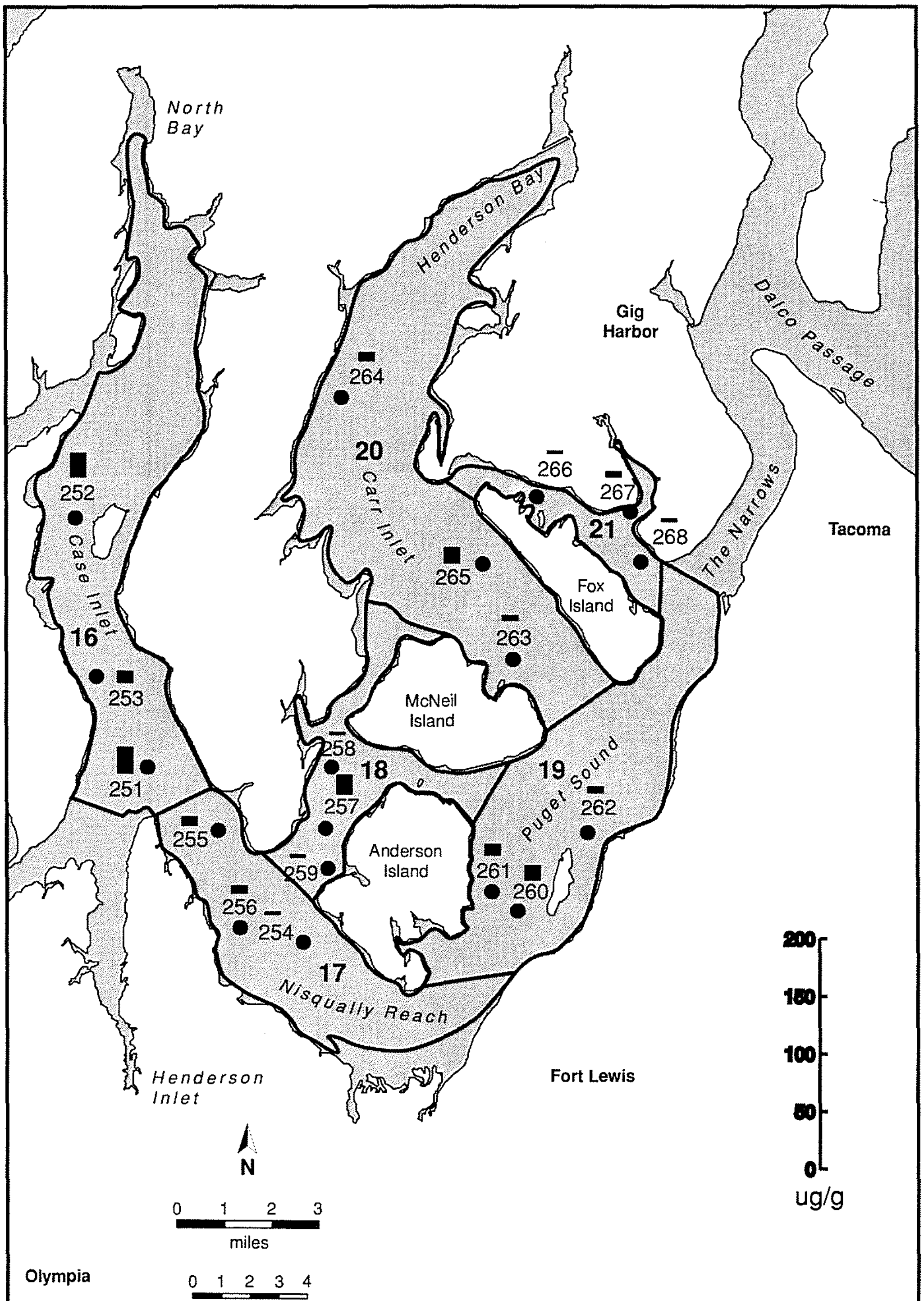


Figure 14. Results of 1999 cytochrome P450 HRGS assays (as B[a]P equivalents (μg/g)) for stations in Case Inlet, Carr Inlet, and vicinity of Anderson and Fox Island (strata 16 through 21). (Strata numbers are shown in bold. Stations are identified as sample number).

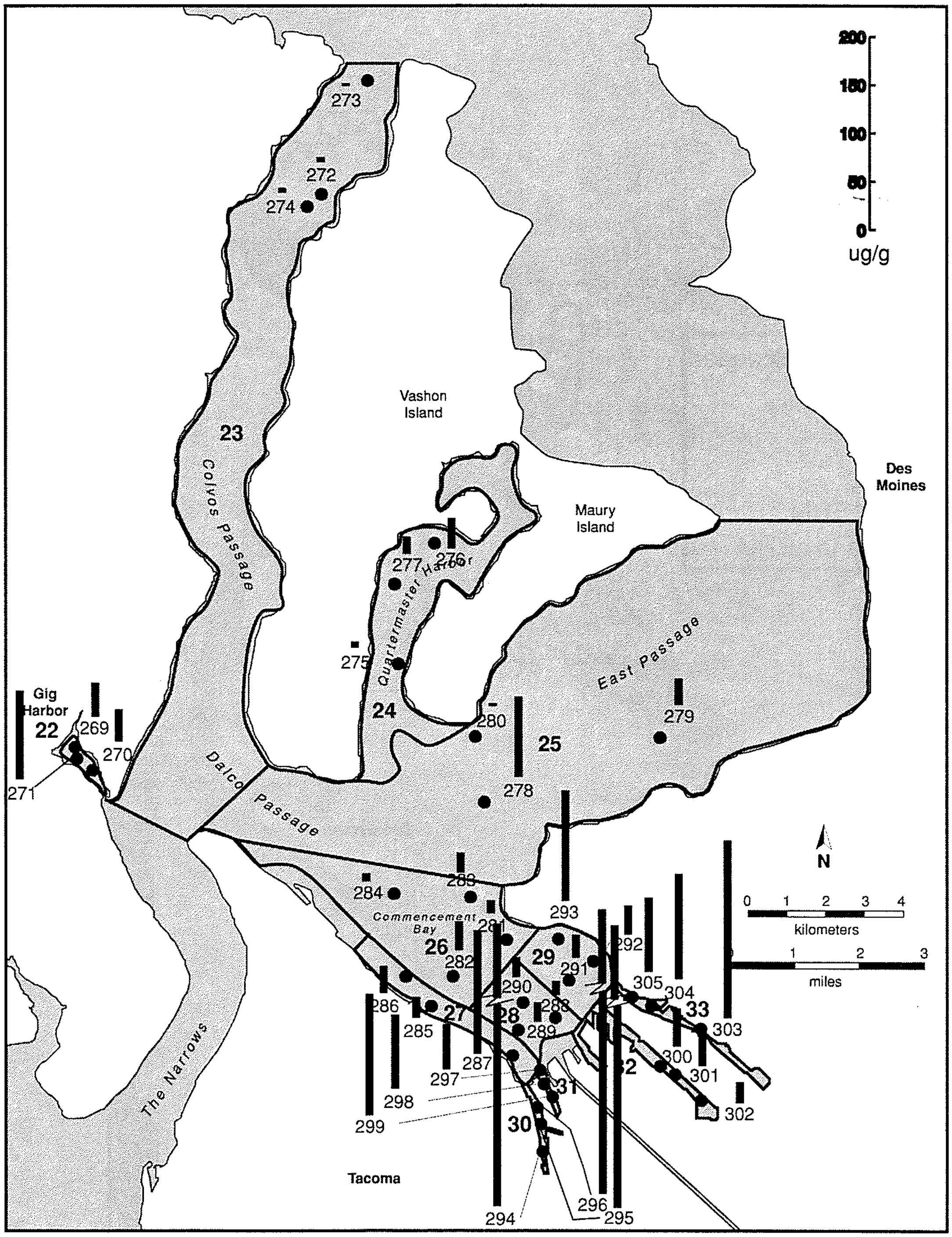


Figure 15. Results of 1999 cytochrome P450 HRGS assays (as B[a]P equivalents (μg /g)) for stations in Colvos Passage, Gig Harbor, Quartermaster Harbor, East Passage, and Commencement Bay (strata 22 through 33). (Strata numbers are shown in bold. Stations are identified as sample number).

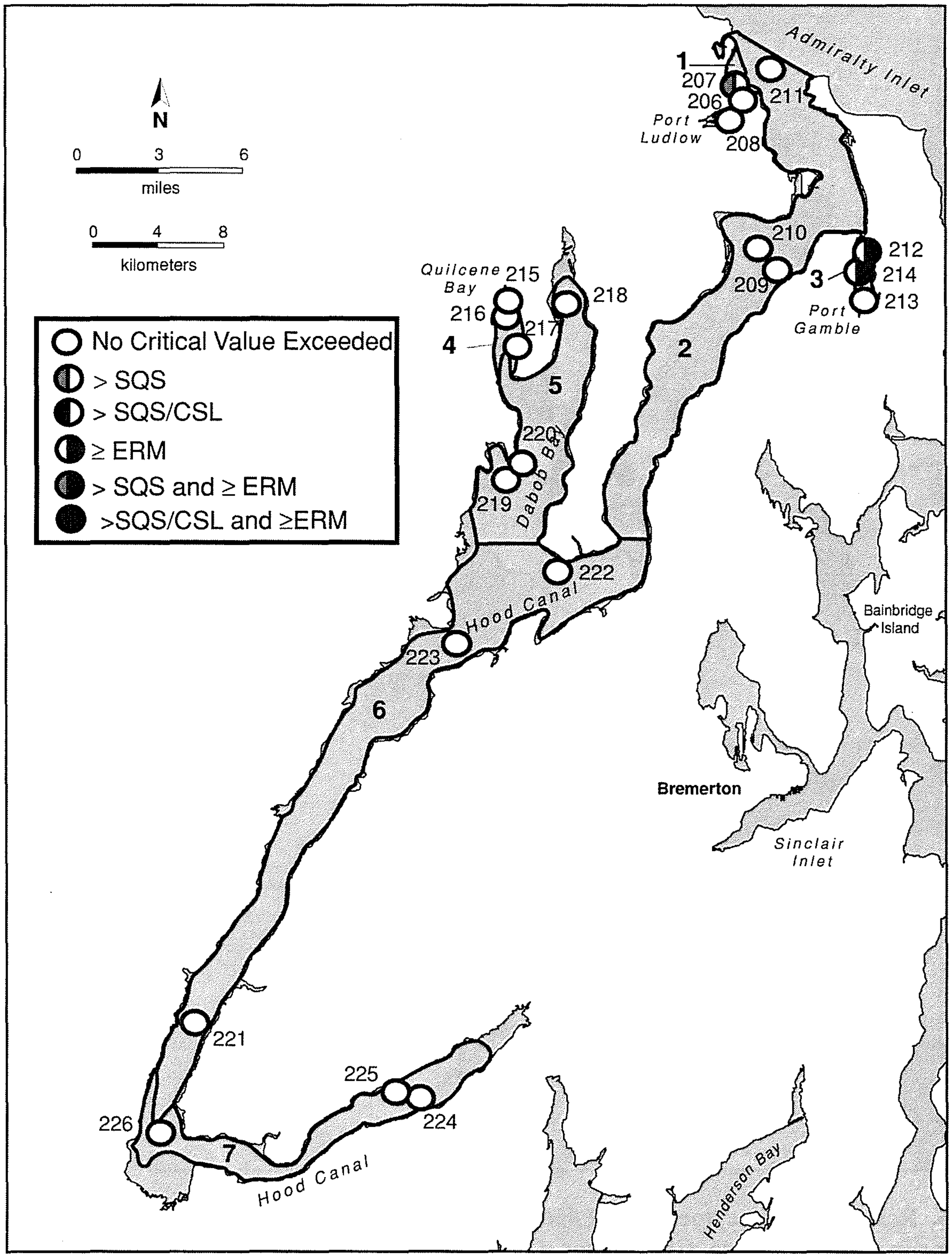


Figure 16. Sampling stations in Admiralty Inlet through Hood Canal (strata 1 through 7) with sediment chemical concentrations exceeding numerical guidelines and Washington State criteria. (Strata numbers are shown in bold. Stations are identified as sample number).

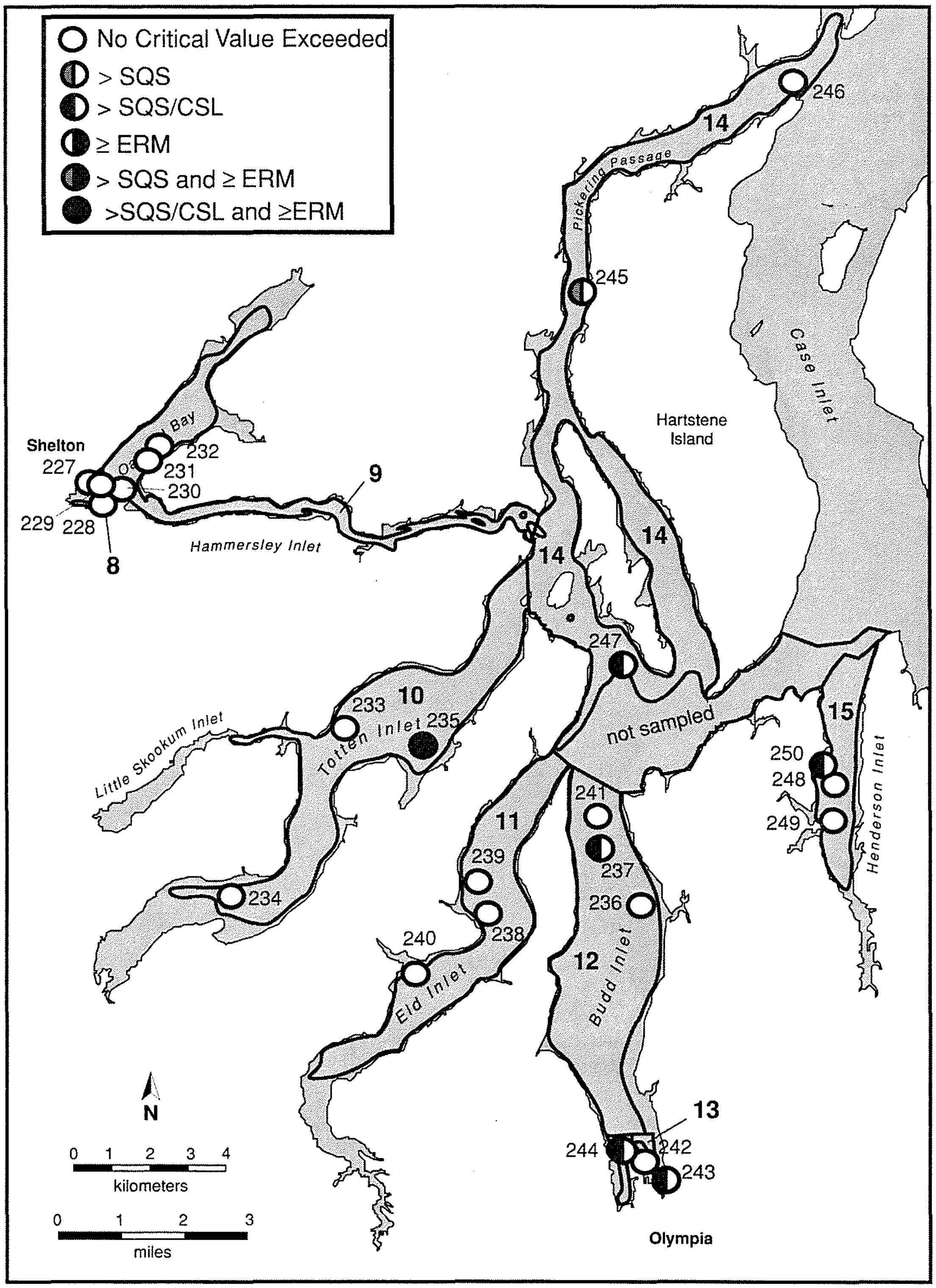


Figure 17. Sampling stations in Pickering Passage through Henderson Inlet (8 through 15) with sediment chemical concentrations exceeding numerical guidelines and Washington State criteria. (Strata numbers are shown in bold. Stations are identified as sample number).

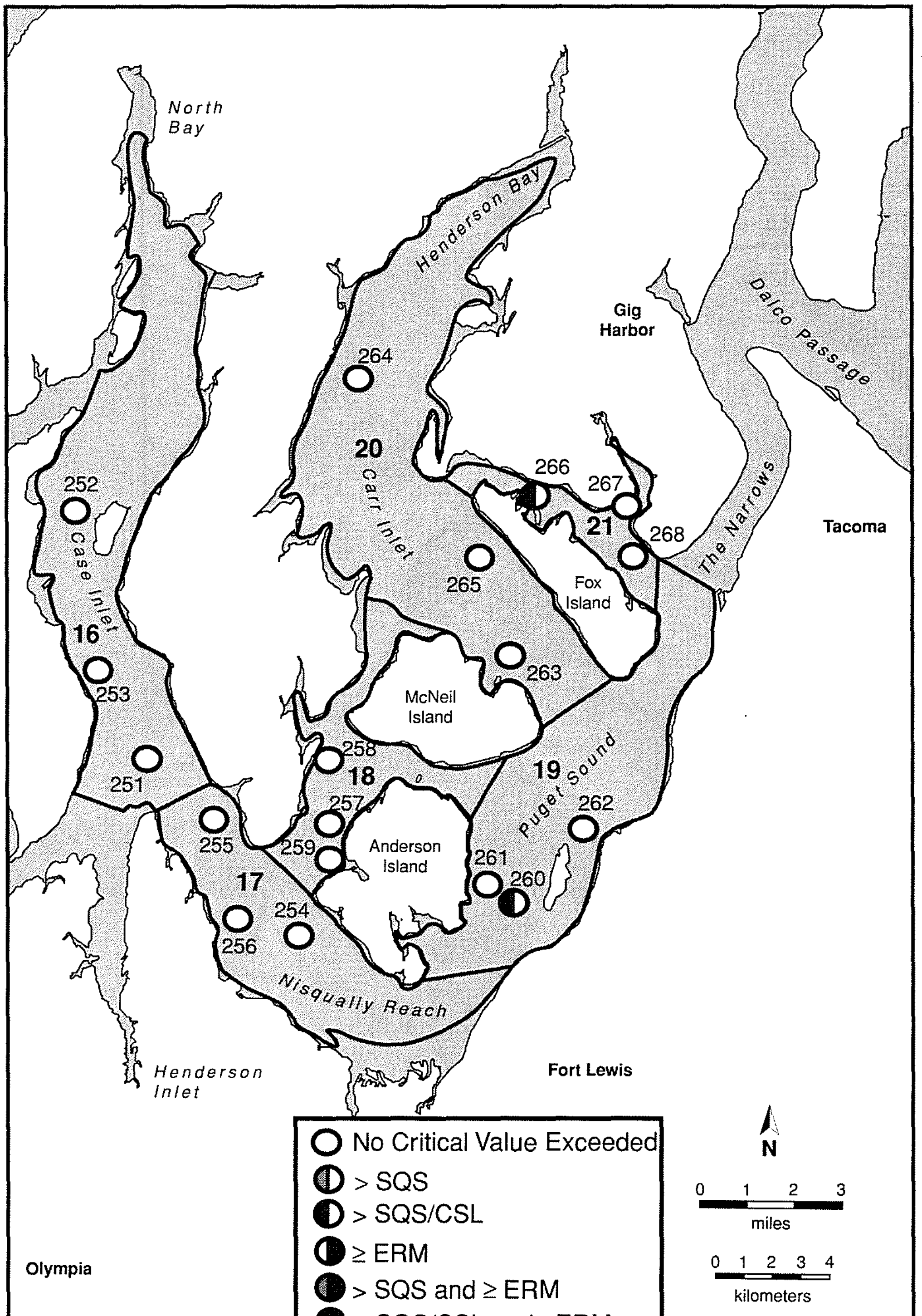


Figure 18. Sampling stations in Case Inlet, Carr Inlet, and vicinity of Anderson and Fox Island (strata 16 through 21) with sediment chemical concentrations exceeding numerical guidelines and Washington State criteria. (Strata numbers are shown in bold. Stations are identified as sample number).

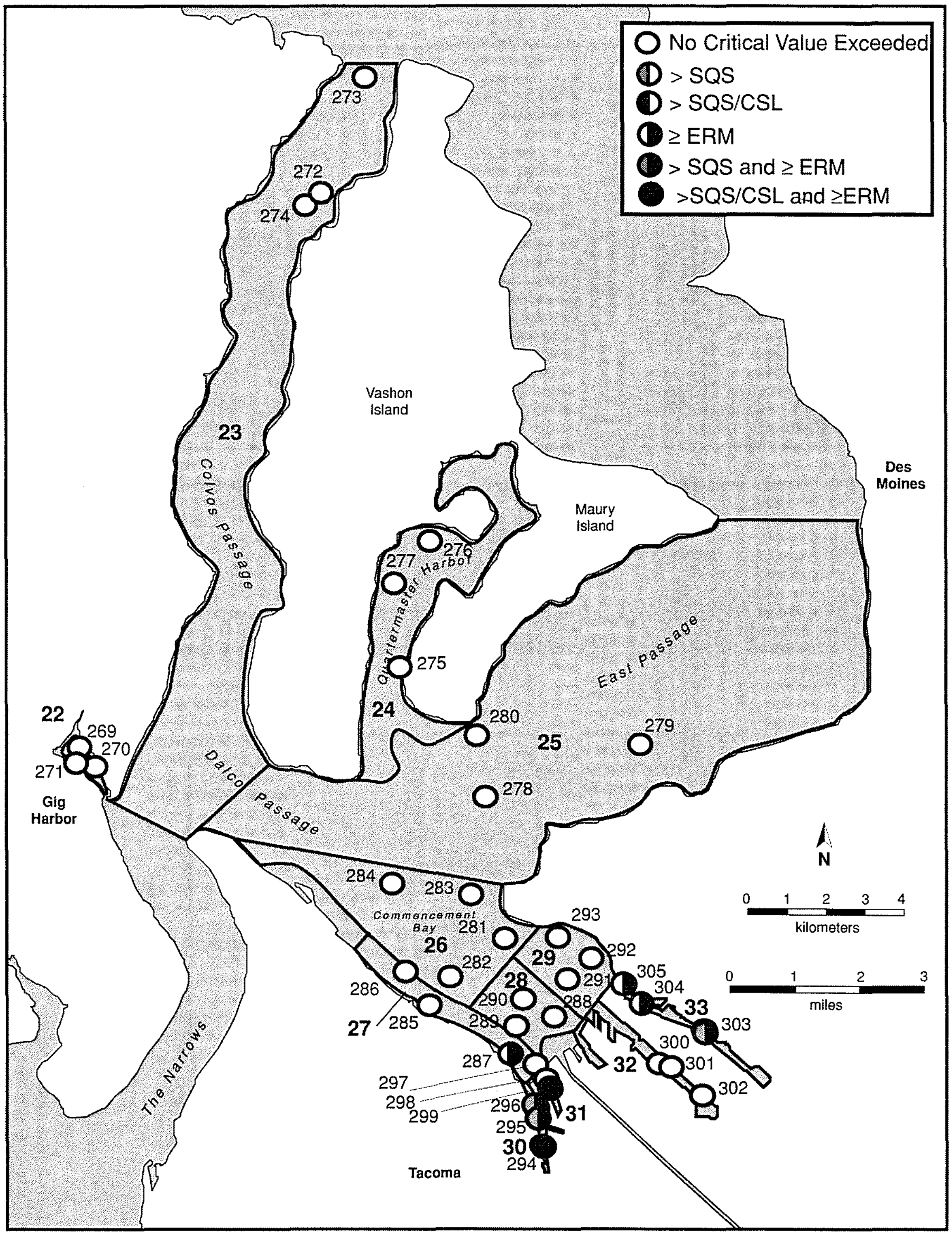


Figure 19. Sampling stations in Colvos Passage, Gig Harbor, Quartermaster Harbor, East Passage, and Commencement Bay (strata 22 through 33) with sediment chemical concentrations exceeding numerical guidelines and Washington State criteria. (Strata numbers are shown in bold. Stations are identified as sample number).

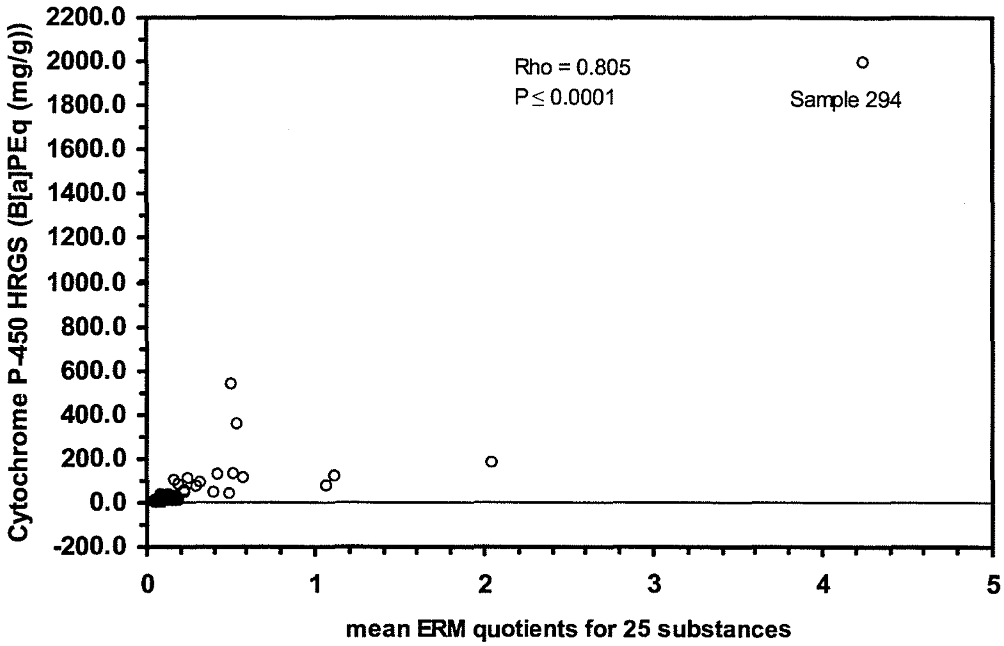


Figure 20. Relationship between cytochrome P450 HRGS response and the mean ERM quotients for 25 chemical substances (definition - p. 23) in southern Puget Sound sediments sampled during 1999.

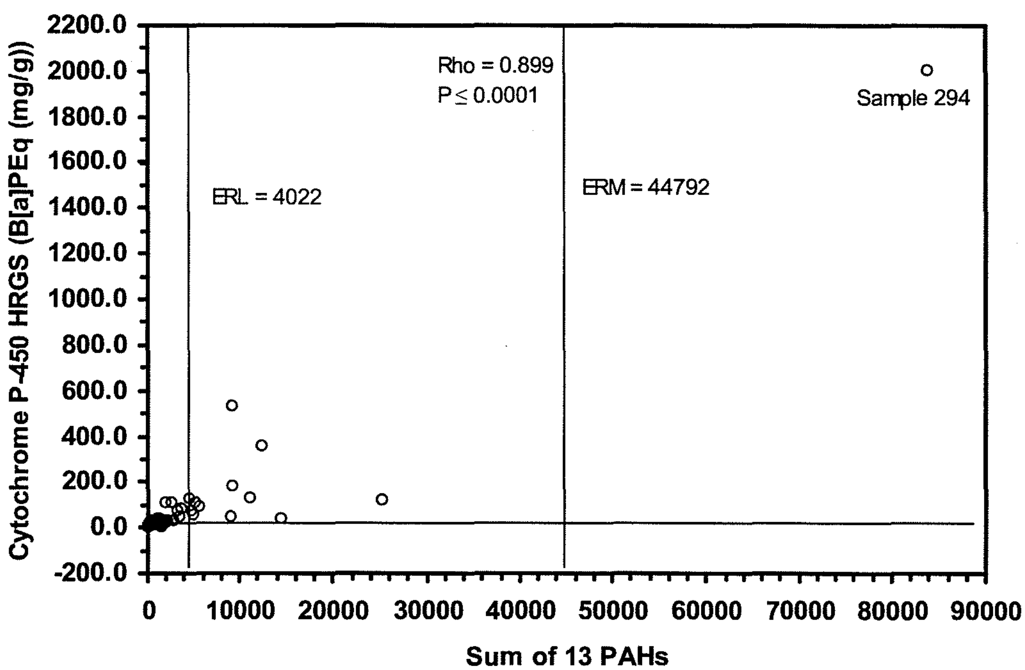


Figure 21. Relationship between cytochrome P450 HRGS response and the sum of 13 polynuclear aromatic hydrocarbons in southern Puget Sound sediments sampled during 1999.

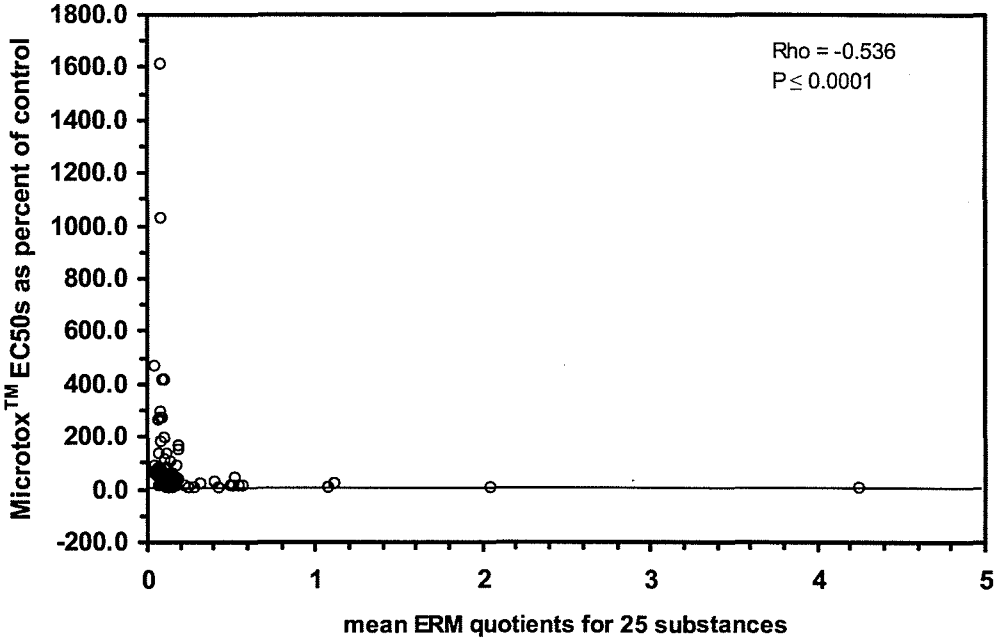


Figure 22. Relationship between microbial bioluminescence and the mean ERM quotients for 25 chemical substances in southern Puget Sound sediments sampled during 1999.

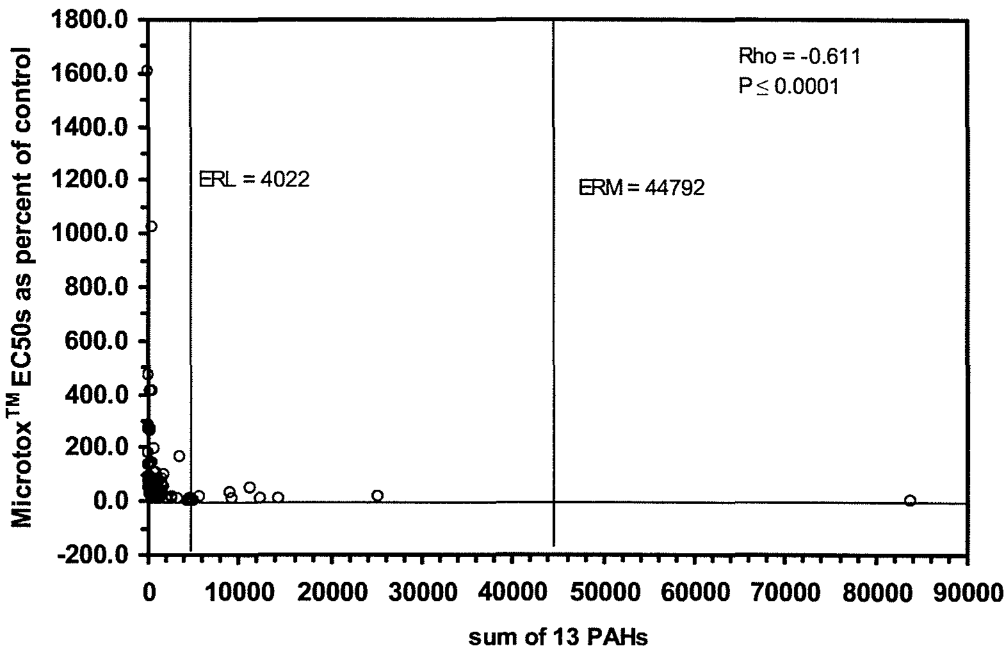


Figure 23. Relationship between microbial bioluminescence and the sum of 13 polynuclear aromatic hydrocarbons in southern Puget Sound sediments sampled during 1999.

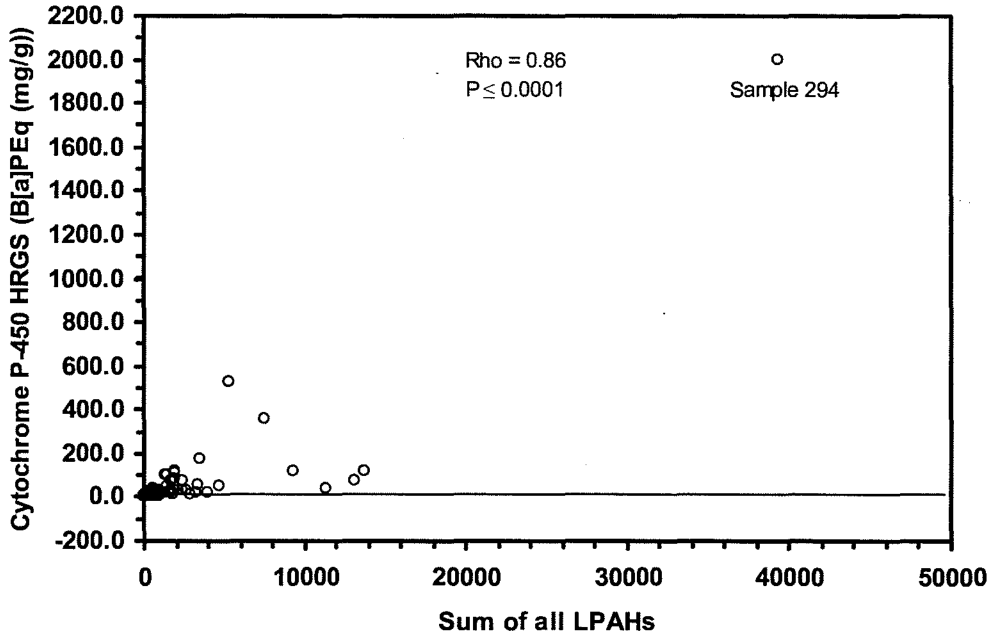


Figure 24. Relationship between cytochrome P450 HRGS response and the sum of all low molecular weight polynuclear aromatic hydrocarbons in southern Puget Sound sediments sampled in 1999.

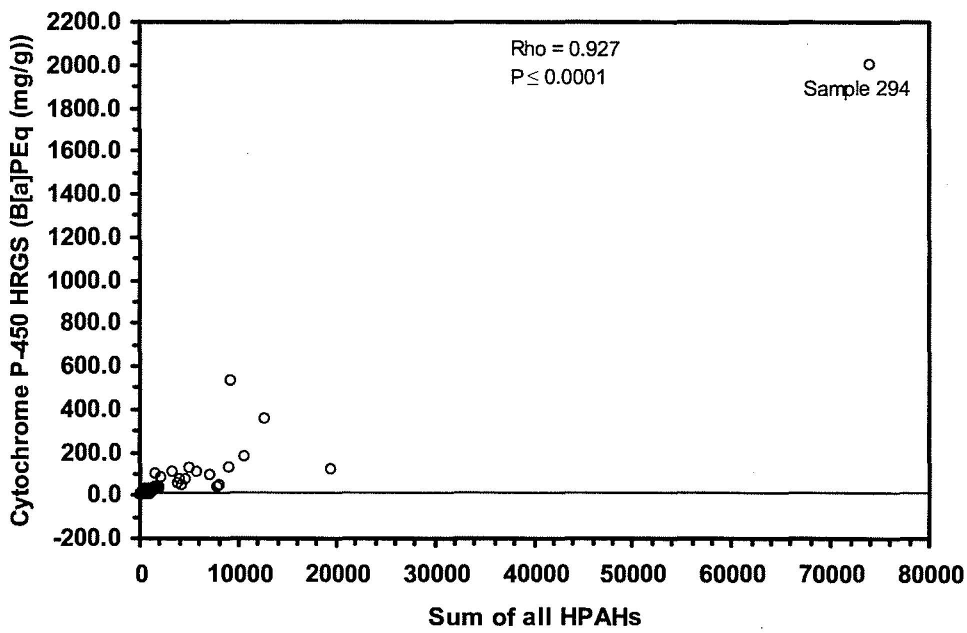


Figure 25. Relationship between cytochrome P450 HRGS response and the sum of all high molecular weight polynuclear aromatic hydrocarbons in southern Puget Sound sediments sampled during 1999.

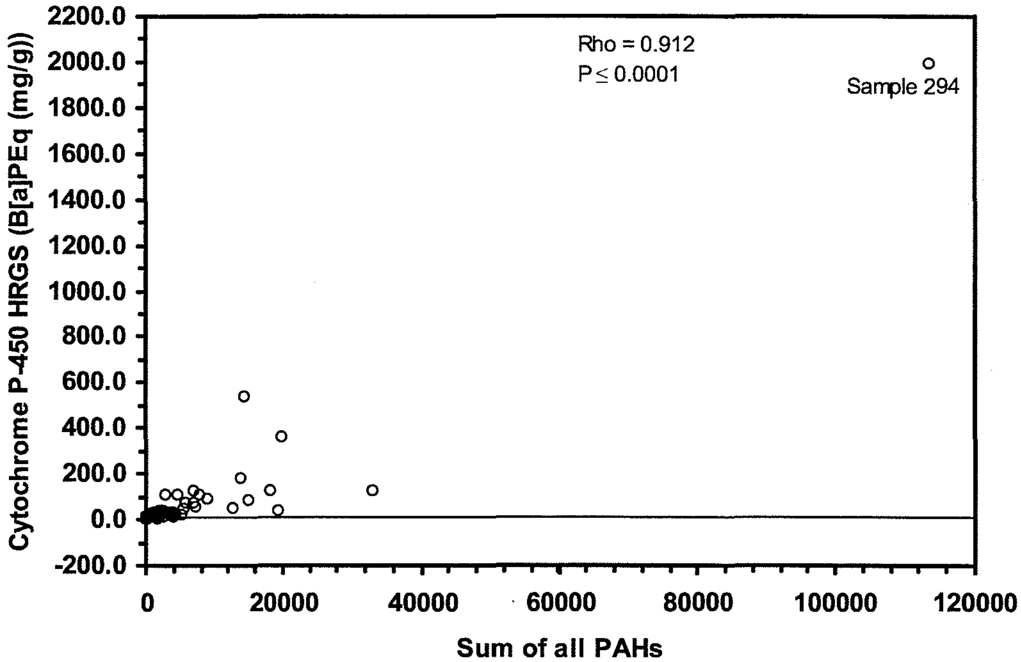


Figure 26. Relationship between cytochrome P450 HRGS response and the total of all polynuclear aromatic hydrocarbons in southern Puget Sound sediments sampled during 1999.

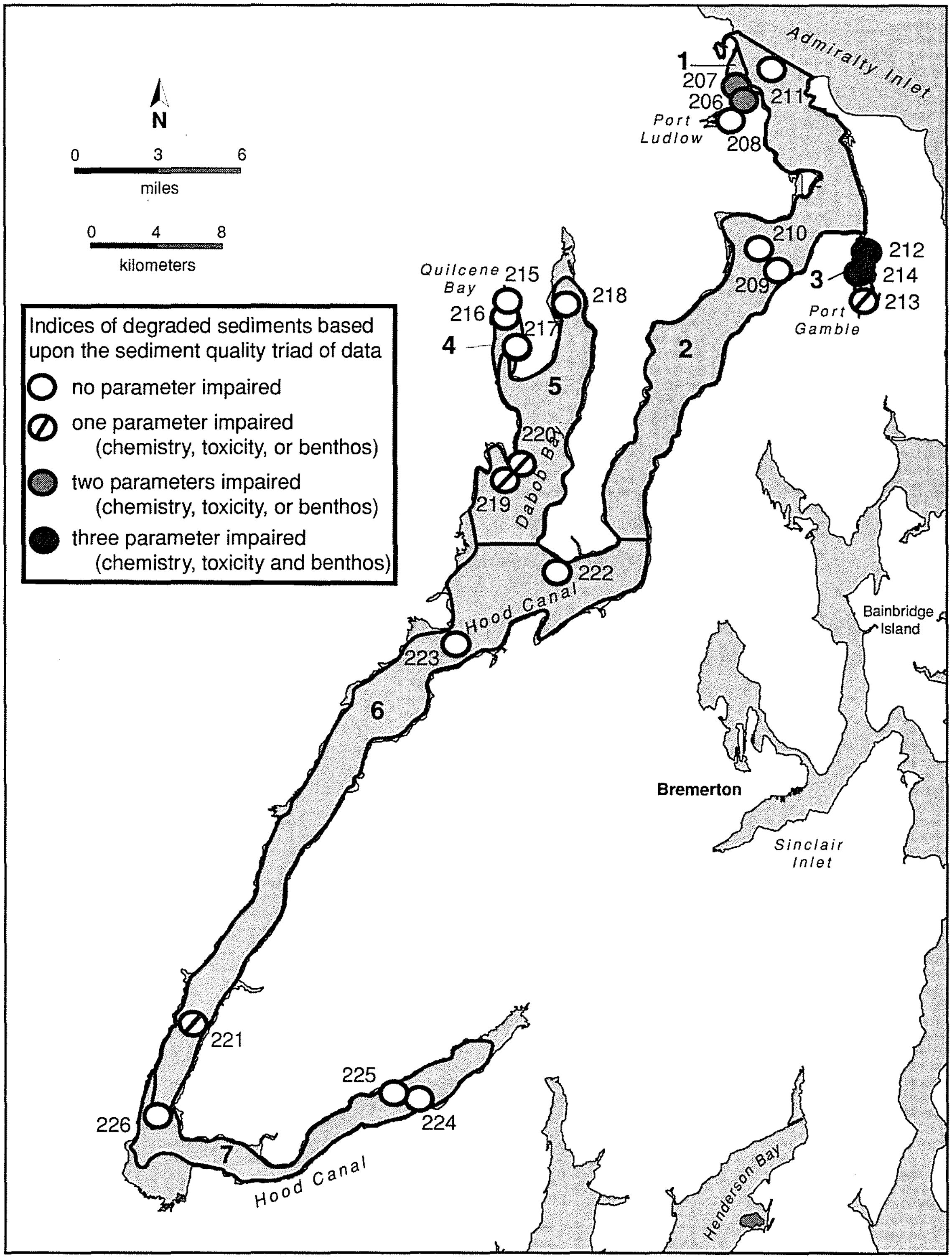


Figure 27. Classification of sediment quality at southern Puget Sound stations sampled during 1999 PSAMP/NOAA survey according to the Sediment Quality Triad of measurements – Admiralty Inlet through Hood Canal (strata 1 through 7). (Strata numbers are shown in bold. Stations are identified as sample number).

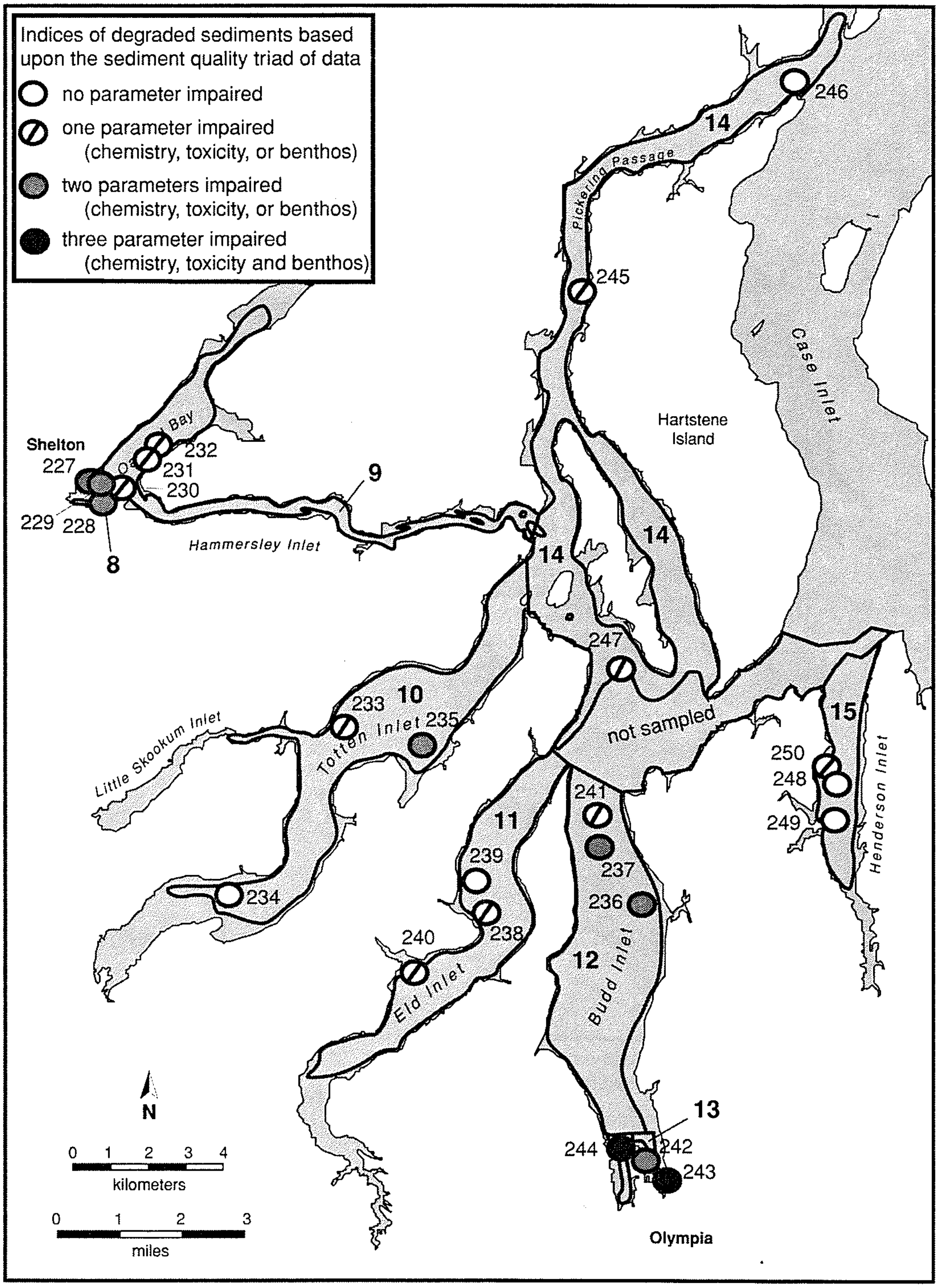


Figure 28. Classification of sediment quality at southern Puget Sound stations sampled during 1999 PSAMP/NOAA survey according to the Sediment Quality Triad of measurements – Pickering Passage through Henderson Inlet (strata 8 through 15). (Strata numbers are shown in bold. Stations are identified as sample number).

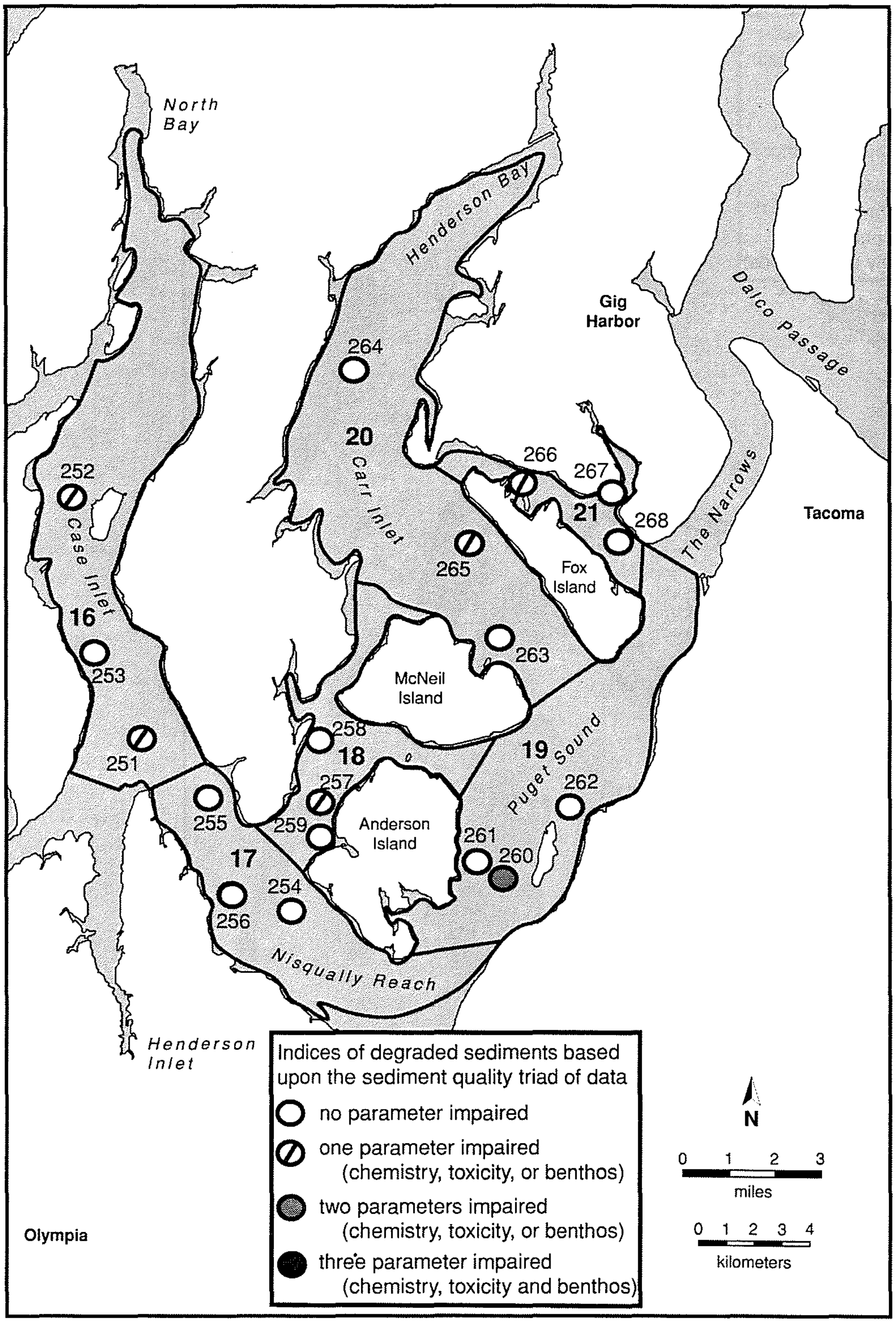


Figure 29. Classification of sediment quality at southern Puget Sound stations sampled during 1999 PSAMP/NOAA survey according to the Sediment Quality Triad of measurements – Case Inlet, Carr Inlet, and vicinity of Anderson and Fox Island (strata 16 through 21). (Strata numbers are shown in bold. Stations are identified as sample number).

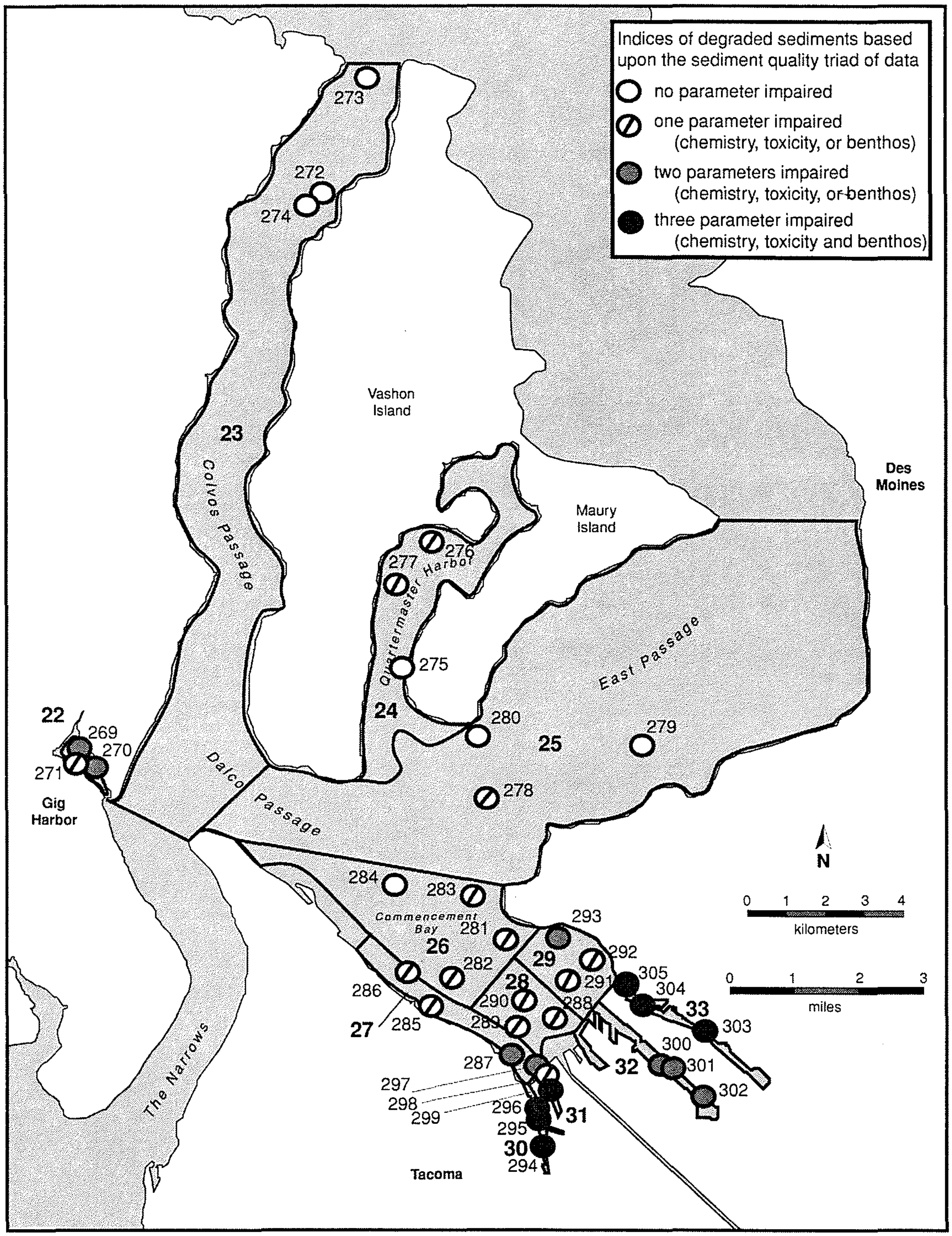


Figure 30. Classification of sediment quality at southern Puget Sound stations sampled during 1999 PSAMP/NOAA survey according to the Sediment Quality Triad of measurements – Colvos Passage, Gig Harbor, Quartermaster Harbor, East Passage, and Commencement Bay (strata 22 through 33). (Strata numbers are shown in bold. Stations are identified as sample number).

Table 1. Southern Puget Sound sampling strata for the PSAMP/NOAA Bioeffects Survey.

Stratum Number	Stratum Name	Area ($857.68\ km^2$)	% of Total Area
1	Port Ludlow	4.69	0.55
2	Hood Canal (north)	107.04	12.48
3	Port Gamble Bay	4.14	0.48
4	Quilcene Bay	2.58	0.30
5	Dabob Bay	55.71	6.50
6	Hood Canal (central)	109.13	12.72
7	Hood Canal (south)	33.10	3.86
8	Port of Shelton	45.70	5.33
9	Oakland Bay	9.82	1.15
10	Totten Inlet	17.15	2.00
11	Eld Inlet	11.99	1.40
12	Budd Inlet	16.36	1.91
13	Port of Olympia	0.81	0.09
14	Pickering Passage/Squaxin Island	31.56	3.68
15	Henderson Inlet	4.93	0.57
16	Case Inlet	62.55	7.29
17	Nisqually Reach	35.73	4.17
18	Drayton Passage	20.16	2.35
19	East Anderson Island/No. Cormorant Passage	49.51	5.77
20	Carr Inlet	79.81	9.31
21	Hale Passage	10.88	1.27
22	Gig Harbor	0.55	0.06
23	Colvos Passage	41.65	4.86
24	Quartermaster Harbor	10.27	1.20
25	East Passage	67.79	7.90
26	Outer Commencement Bay	12.96	1.51
27	S. E. Commencement Bay (shoreline)	2.36	0.27
28	S. E. Commencement Bay	3.16	0.37
29	N.E. Commencement Bay	3.32	0.39
30	Thea Foss Waterway	0.38	0.04
31	Middle Waterway	0.05	0.01
32	Blair Waterway	1.16	0.14
33	Hylebos Waterway	0.67	0.08

Table 2. Chemical and physical parameters measured for sediments collected from southern Puget Sound.

<u>**Related Parameters**</u>
Grain Size
Total organic carbon

<u>**Metals**</u>
Ancillary Metals
Aluminum
Barium
Calcium
Cobalt
Iron
Magnesium
Manganese
Potassium
Sodium
Vanadium

Priority Pollutant Metals
Antimony
Arsenic
Beryllium
Cadmium
Chromium
Copper
Lead
Mercury
Nickel
Selenium
Silver
Thallium
Zinc

Major Elements
Silicon

Trace Elements
Tin

<u>**Organics**</u>
Chlorinated Alkanes
Hexachlorobutadiene

Chlorinated and Nitro-Substituted Phenols
Pentachlorophenol

Chlorinated Aromatic Chemicals
1,2,4-trichlorobenzene
1,2-dichlorobenzene
1,3-dichlorobenzene
1,4-dichlorobenzene
2-chloronaphthalene
Hexachlorobenzene

Chlorinated Pesticides
2,4'-DDD
2,4'-DDE
2,4'-DDT
4,4'-DDD
4,4'-DDE
4-4'DDT
Aldrin
Alpha-chlordane
Alpha-HCH
Beta-HCH
Chlorpyrifos
Cis-nonachlor
Delta-HCH
Dieldrin
Endosulfan I (Alpha-endosulfan)
Endosulfan II (Beta-endosulfan)
Endosulfan sulfate
Endrin
Endrin ketone
Endrin aldehyde
Gamma-chlordane
Gamma-HCH
Heptachlor
Heptachlor epoxide
Methoxychlor
Mirex
Oxychlordane
Toxaphene
Trans-nonachlor

Table 2. Concluded.

Polynuclear Aromatic Hydrocarbons
LPAHs
1,6,7-Trimethylnaphthalene
1-Methylnaphthalene
1-Methylphenanthrene
2,6-Dimethylnaphthalene
2-methylnapthalene
2-methylphenanthrene
Acenaphthene
Acenaphthylene
Anthracene
Biphenyl
C1 - C3 Fluorenes
C1 - C3 Dibenzothiophenes
C1 - C4 naphthalenes
C1 - C4 Phenanthrenes
Dibenzothiophene
Fluorene
Naphthalene
Phenanthrene
Retene
calculated value:
LPAH
HPAHs
Benzo(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(e)pyrene
Benzo(g,h,i)perylene
Benzo(k)fluoranthene
C1 - C4 Chrysene
C1- Fluoranthene
Chrysene
Dibenzo(a,h)anthracene
Fluoranthene
Indeno(1,2,3-c,d)pyrene
Perylene
Pyrene
calculated values:
total Benzofluoranthenes
HPAH

Miscellaneous Extractable Chemicals
Benzoic acid
Benzyl alcohol
Dibenzofuran

Organonitrogen Chemicals
N-nitrosodiphenylamine
9(H) Carbazole

Organotins
Butyl tins: Di-, Mono-, Tetra-, Tri-butyltin

Phenols
2,4-dimethylphenol
2-methylphenol
4-methylphenol
Phenol
P-nonylphenol

Phthalate Esters
Bis(2-ethylhexyl)phthalate
Butyl benzyl phthalate
Diethyl phthalate
Dimethyl phthalate
Di-n-butyl phthalate
Di-n-octyl phthalate

Polychlorinated Biphenyls

PCB Congeners:	180
8	187
18	195
28	206
44	209
52	
66	**PCB Aroclors:**
77	1016
101	1221
105	1232
118	1242
126	1248
128	1254
128	1260
153	1262
170	1268

Table 3. Chemistry Parameters: Laboratory analytical methods and reporting limits.

Parameter	Method	Reference	Practical Quantitation Limit
Grain Size	Sieve-pipette method	PSEP, 1996a	>2000 to <3.9 microns
Total Organic Carbon	Conversion to CO_2 measured by nondispersive infra-red spectroscopy	PSEP, 1986	0.1 %
Metals (Partial digestion)	Strong acid (aqua regia) digestion and analyzed via ICP, ICP-MS, or GFAA, depending upon the analyte	- digestion - PSEP, 1996c EPA 3050 - analysis - PSEP, 1996c (EPA 200.8, 206.2, 270.2), (SW6010)	1-10 ppm
Metals (Total digestion)	Hydrofluoric acid-based digestion and analyzed via ICP or GFAA, depending upon the analyte	- digestion - PSEP, 1996c EPA 3052 - analysis - PSEP, 1996c (EPA 200.8, 206.2, 270.2), (SW6010)	1-10 ppm
Mercury	Cold Vapor Atomic Absorption	PSEP, 1996c EPA 245.5	1-10 ppm
Butyl Tins	Solvent Extraction, Derivitization, Gas Chromatography/Mass Spectrometry in selected ion mode	Manchester Method (Manchester Environmental Laboratory, 1997)	40 µg/kg
Base/Neutral/Acid Organic Chemicals	Capillary column Gas Chromatography/ Mass Spectrometry	PSEP 1996d, EPA 8270 & 8081	100-200 ppb
Polynuclear Aromatic Hydrocarbons (PAH)	Capillary column Gas Chromatography/ Mass Spectrometry	PSEP 1996d, extraction following Manchester modification of EPA 8270	100-200 ppb
Chlorinated Pesticides and PCB (Aroclors)	Gas Chromatography Electron Capture Detection	PSEP 1996d, EPA 8081	1-5 ppb
PCB Congeners	Gas Chromatography Electron Capture Detection	Lauenstein, G. G. and A. Y. Cantillo, 1993, EPA 8081	1-5 ppb

Table 4. Chemistry parameters: Field analytical methods and resolution.

Parameter	Method	Resolution
Temperature	Mercury Thermometer	1.0 °C
Surface salinity	Refractometer	1.0 ppt

Table 5. Benthic infaunal indices calculated to characterize the infaunal invertebrate assemblages identified from each PSAMP/NOAA sampling station.

Infaunal index	Definition	Calculation
Total Abundance	A measure of density equal to the total number of organisms per sample area	Sum of all organisms counted in each sample
Major Taxa Abundance	A measure of density equal to the total number of organisms in each major taxa group (Annelida, Mollusca, Echinodermata, Arthropoda, Miscellaneous Taxa) per sample area	Sum of all organisms counted in each major taxa group per sample
Taxa Richness	Total number of taxa (taxa = lowest level of identification for each organism) per sample area	Sum of all taxa identified in each sample
Pielou's Evenness (J') (Pielou, 1966, 1974)	Relates the observed diversity in benthic assemblages as a proportion of the maximum possible diversity for the data set (the equitability (evenness) of the distribution of individuals among species)	$J' = H'/\log s$ Where: $H' = -\sum_{i=1}^{s} p_i \log p_i$ where p_i = the proportion of the assemblage that belongs to the ith species ($p=n_i/N$, where n_I=the number of individuals in the i species and N= total number of individuals), and where s = the total number of species
Swartz's Dominance Index (SDI)(Swartz et al., 1985)	The minimum number of taxa whose combined abundance accounted for 75 percent of the total abundance in each sample	Sum of the minimum number of taxa whose combined abundance accounted for 75 percent of the total abundance in each sample

Table 6. Results of amphipod survival tests for 100 sediment samples from southern Puget Sound. Tests performed with *Ampelisca abdita*.

Stratum	Location	Sample	Mean Amphipod survival (%)	Mean Amphipod survival as % of control	Statistical significance
1	Port Ludlow	206	90	103.00	
		207	84	97.00	
		208	84	93.33	
2	Hood Canal (north)	209	96	106.67	
		210	88	108.64	
		211	84	103.70	
3	Port Gamble Bay	212	87	100.00	
		213	85	98.00	
		214	89	102.30	
4	Quilcene Bay	215	87	100.00	
		216	84	96.55	
		217	90	103.00	
5	Dabob Bay	218	85	98.00	
		219	87	100.00	
		220	86	98.85	
6	Hood Canal (central)	221	90	100.00	
		222	88	101.15	
		223	88	101.15	
7	Hood Canal (south)	224	86	95.56	
		225	87	96.67	
		226	95	105.56	
8	Port of Shelton	227	96	103.23	
		228	94	101.08	
		229	97	104.30	
9	Oakland Bay	230	93	97.89	

Table 6. Continued.

Stratum	Location	Sample	Mean Amphipod survival (%)	Mean Amphipod survival as % of control	Statistical significance
		231	96	101.05	
		232	95	102.15	
10	Totten Inlet	233	97	100.00	
		234	94	96.91	
		235	97	100.00	
11	Eld Inlet	238	97	100.00	
		239	98	101.03	
		240	95	97.94	
12	Budd Inlet	236	94	96.91	
		237	96	101.05	
		241	97	102.11	
13	Port of Olympia	242	92	96.84	
		243	96	101.05	
		244	94	98.95	
14	Pickering Passage/Squaxin Island	245	77	81.05	*
		246	96	101.05	
		247	94	98.95	
15	Henderson Inlet	248	91	93.81	
		249	97	100.00	
		250	95	97.94	
16	Case Inlet	251	97	100.00	
		252	95	97.94	
		253	95	97.94	
17	Nisqually Reach	254	89	91.75	*
		255	94	96.91	
		256	94	95.92	

Table 6. Continued.

Stratum	Location	Sample	Mean Amphipod survival (%)	Mean Amphipod survival as % of control	Statistical significance
18	Drayton Passage	257	94	96.91	
		258	95	97.94	
		259	99	102.06	
19	East Anderson Island/No. Cormorant Passage	260	97	98.98	
		261	97	98.98	
		262	96	97.96	
20	Carr Inlet	263	99	101.02	
		264	99	101.02	
		265	97	98.98	
21	Hale Passage	266	99	101.02	
		267	98	100.00	
		268	97	98.98	
22	Gig Harbor	269	92	104.55	
		270	86	97.73	
		271	88	100.00	
23	Colvos Passage	272	84	97.00	
		273	79	91.00	
		274	82	91.11	
24	Quartermaster Harbor	275	87	98.86	
		276	93	105.68	
		277	83	94.32	
25	East Passage	278	91	103.41	
		279	88	100.00	
		280	86	97.73	
26	Outer Commencement Bay	281	87	98.86	
		282	92	100.00	
		283	87	94.57	

Table 6. Concluded.

Stratum	Location	Sample	Mean Amphipod survival (%)	Mean Amphipod survival as % of control	Statistical significance
		284	93	101.09	
27	S. E. Commencement Bay (shoreline)	285	93	101.09	
		286	94	102.17	
		287	88	95.65	
28	S. E. Commencement Bay	288	94	101.08	
		289	96	104.35	
		290	92	100.00	
29	N.E. Commencement Bay	291	87	96.67	
		292	84	95.45	
		293	83	92.22	
30	Thea Foss Waterway	294	83	90.22	*
		295	94	101.08	
		296	89	95.70	
31	Middle Waterway	297	93	100.00	
		298	88	94.62	
		299	87	93.55	
32	Blair Waterway	300	89	101.14	
		301	84	93.33	
		302	85	94.44	
33	Hylebos Waterway	303	89	101.14	
		304	91	101.11	
		305	77	86.00	

*Mean percent survival significantly less than CLIS controls ($p < 0.05$)
**Mean percent survival significantly less than CLIS controls ($p < 0.05$) and less than 80% of CLIS controls

Table 7. Results of sea urchin fertilization tests on pore waters from 100 sediment samples from southern Puget Sound. Tests performed with *Strongylocentrotus purpuratus*.

Stratum and Location	Sample	100 % pore water			50 % pore water			25 % pore water		
		Mean % fertilization	% of control	Statistical significance	Mean % fertilization	% of control	Statistical significance	Mean % fertilization	% of control	Statistical significance
1	206	99.2	107		98.2	100.0		98.2	100.9	
Port Ludlow	207	99.0	107		96.6	98.4		97.2	99.9	
	208	76.0	82	+	97.8	99.6		98.0	100.7	
2	209	98.0	105		98.8	100.6		99.0	101.7	
Hood Canal (north)	210	98.6	106		98.0	99.8		98.6	101.3	
	211	98.2	106		98.5	100.3		98.2	100.9	
3	212	98.4	106		97.6	99.4		98.2	100.9	
Port Gamble Bay	213	99.4	107		98.8	100.6		98.4	101.1	
	214	66.4	71	**	99.0	100.8		98.0	100.7	
4	215	94.0	101		97.0	98.8		96.6	99.3	
Quilcene Bay	216	97.0	104		98.2	100.0		97.6	100.3	
	217	98.4	106		96.6	98.4		98.2	100.9	
5	218	98.2	106		98.4	100.2		97.2	99.9	
Dabob Bay	219	38.0	41	**	82.6	84.1	+	96.4	99.1	
	220	42.2	45	**	90.4	92.1	++	99.0	101.7	
6	221	99.0	107		98.0	99.8		97.6	100.3	
Hood Canal (central)	222	97.8	105		99.0	100.8		98.4	101.1	
	223	98.2	106		99.6	101.4		98.2	100.9	
7	224	98.2	106		98.6	100.4		95.2	97.8	
Hood Canal (south)	225	98.8	106		98.8	100.6		98.8	101.5	
	226	95.8	103		97.4	99.2		96.8	99.5	

Table 7. Continued.

Stratum and Location	Sample	100 % pore water			50 % pore water			25 % pore water		
		Mean % fertili-zation	% of control	Stati-stical signifi-cance	Mean % fertili-zation	% of control	Stati-stical signifi-cance	Mean % fertili-zation	% of control	Stati-stical signifi-cance
8	227	90.6	98		96.0	97.8		96.0	98.7	
Port of Shelton	228	91.8	99		93.4	95.1	++	93.4	96.0	
	229	92.2	99		93.4	95.1	++	88.8	91.3	++
9	230	88.8	96		95.4	97.1		87.6	90.0	++
Oakland Bay	231	94.6	102		94.6	96.3		90.8	93.3	++
	232	78.4	84	+	86.8	88.4	++	89.6	92.1	++
10	233	98.6	106		97.2	99.0		97.6	100.3	
Totten Inlet	234	95.2	102		99.0	100.8		95.4	98.0	
	235	65.2	70	**	90.6	92.3	++	93.2	95.8	
11	238	99.4	107		98.2	100.0		99.0	101.7	
Eld Inlet	239	99.0	107		99.0	100.8		98.4	101.1	
	240	7.2	8	**	31.2	31.8	**	82.0	84.3	**
12	236	86.0	93		97.2	99.0		97.6	100.3	
Budd Inlet	237	96.2	104		98.6	100.4		97.6	100.3	
	241	98.4	106		99.2	101.0		97.8	100.5	
13	242	0.4	0	**	0.0	0.0	**	0.2	0.2	**
Port of Olympia	243	0.0	0	**	0.4	0.4	**	3.8	3.9	**
	244	93.0	100		96.8	98.6		96.8	99.5	
14	245	98.8	106		97.8	99.6		97.8	100.5	
Pickering Passage/Squaxin Island	246	99.0	107		98.8	100.6		98.8	101.5	
	247	98.8	106		98.6	100.4		99.2	102.0	
15	248	96.4	104		93.8	95.5	+	82.8	85.1	++
Henderson Inlet	249	99.4	107		97.8	99.6		92.4	95.0	
	250	97.2	105		88.2	89.8	++	75.4	77.5	++

Table 7. Continued.

Stratum and Location	Sample	100 % pore water			50 % pore water			25 % pore water		
		Mean % fertilization	% of control	Statistical significance	Mean % fertilization	% of control	Statistical significance	Mean % fertilization	% of control	Statistical significance
16	251	95.2	102		96.8	98.6		96.6	99.3	
Case Inlet	252	78.2	84	+	96.2	98.0		97.6	100.3	
	253	94.2	101		97.4	99.2		97.2	99.9	
17	254	100.0	101		99.2	100.4		98.2	99.6	
Nisqually Reach	255	99.8	101		99.6	100.8		99.2	100.6	
	256	98.8	100		99.4	100.6		99.2	100.6	
18	257	99.2	101		98.2	99.4		99.0	100.4	
Drayton Passage	258	98.8	100		99.6	100.8		98.8	100.2	
	259	99.6	101		98.8	100.0		99.2	101.0	
19	260	98.8	100		98.4	100.0		98.8	100.0	
East Anderson	261	98.6	100		99.6	100.8		99.0	100.4	
Island/No. Cormorant Passage	262	96.6	98		99.0	100.2		99.6	101.0	
20	263	99.0	100		98.8	100.0		99.0	100.4	
Carr Inlet	264	99.4	101		98.2	99.4		98.6	100.0	
	265	97.4	99		98.8	100.0		99.8	101.2	
21	266	99.2	101		98.2	99.4		99.8	101.2	
Hale Passage	267	98.8	100		99.4	100.6		97.2	98.6	
	268	98.6	100		98.8	100.0		99.4	100.8	
22	269	99.6	101		99.0	100.2		99.2	100.6	
Gig Harbor	270	99.2	101		99.2	100.4		98.4	99.8	
	271	99.4	101		99.4	100.6		99.4	100.8	
23	272	99.2	101		99.6	100.8		99.0	100.4	
Colvos Passage	273	99.0	100		98.0	99.2		99.0	100.4	

Table 7. Continued.

Stratum and Location	Sample	100 % pore water			50 % pore water			25 % pore water		
		Mean % fertili-zation	% of control	Stati-stical signifi-cance	Mean % fertili-zation	% of control	Stati-stical signifi-cance	Mean % fertili-zation	% of control	Stati-stical signifi-cance
	274	99.2	101		99.2	100.4		98.8	100.2	
24	275	98.4	100		99.4	100.6		99.2	100.6	
Quartermaster Harbor	276	98.2	99		99.2	100.4		99.2	100.6	
	277	99.2	101		98.6	99.8		98.4	99.8	
25	278	99.6	101		99.0	100.2		99.6	101.0	
East Passage	279	98.8	100		99.6	100.8		98.8	100.2	
	280	97.4	99		98.8	100.0		98.4	99.8	
26	281	98.8	100		98.6	99.8		99.0	100.4	
Outer Commencement Bay	282	97.6	99		99.2	100.4		98.4	99.8	
	283	99.2	101		99.4	100.6		99.2	100.6	
	284	99.2	101		99.2	100.4		99.4	100.8	
27	285	99.4	101		99.2	100.4		100.0	101.4	
S. E. Commencement Bay (shoreline)	286	99.4	101		99.8	101.0		99.6	101.0	
	287	98.8	100		99.8	101.0		99.8	101.2	
28	288	99.6	101		99.6	100.8		99.0	100.4	
S. E. Commencement Bay	289	100.0	101		99.2	100.4		99.4	100.8	
	290	99.6	101		99.4	100.6		99.2	100.6	
29	291	99.2	101		99.4	100.6		99.0	100.4	
N.E. Commencement Bay	292	98.2	99		99.0	100.2		99.2	100.6	
	293	98.0	99		98.6	99.8		99.4	100.8	

Table 7. Concluded.

Stratum and Location	Sample	100 % pore water			50 % pore water			25 % pore water		
		Mean % fertili-zation	% of control	Stati-stical signifi-cance	Mean % fertili-zation	% of control	Stati-stical signifi-cance	Mean % fertili-zation	% of control	Stati-stical signifi-cance
30	294	28.4	29	**	78.2	79.1	**	91.6	92.9	++
Thea Foss Waterway	295	99.2	101		99.6	100.8		99.8	101.2	
	296	99.4	101		99.4	100.6		99.2	100.6	
31	297	97.8	99		99.0	100.2		99.5	100.9	
Middle Waterway	298	99.7	101		99.8	101.0		99.2	100.6	
	299	99.0	100		99.6	100.8		99.6	101.0	
32	300	99.6	101		99.4	100.6		99.4	100.8	
Blair Waterway	301	98.8	100		98.8	100.0		99.2	100.6	
	302	99.4	101		98.4	99.6		98.8	100.2	
33	303	97.0	98		98.8	100.0		96.8	98.2	
Hylebos Waterway	304	98.4	100		99.2	100.4		97.8	99.2	
	305	99.4	101		98.6	99.8		97.6	99.0	

Mean response significantly different from controls (Dunnett's t-test: +=alpha<0.05 or ++=alpha<0.01)
Mean response significantly different from controls (Dunnett's t-test) and < 80% of controls (*=alpha<0.05 or **=alpha<0.01)

Table 8. Results of Microtox™ tests (as mean mg/ml and percent of Redfish Bay control) and cytochrome P450 HRGS bioassays (as benzo[a]pyrene equivalents) of 100 sediment samples from southern Puget Sound.

			Microtox™ EC50					
Stratum	Location	Sample	mean (mg/ml)	Statistical significance	% of control	Statistical significance	HRGS as B[a]P eq (μg/g)	Statistical significance
1	Port Ludlow	206	0.97		9	**	102.9	+++
		207	6.87		63	**	4.4	
		208	2.00		18	**	6.0	
2	Hood Canal (north)	209	7.40		68	**	6.7	
		210	8.60		79		6.7	
		211	7.27		67	**	5.1	
3	Port Gamble Bay	212	2.23		20	**	15.0	++
		213	1.70		16	**	8.2	
		214	0.99		9	**	36.8	+++
4	Quilcene Bay	215	4.43		41		5.3	
		216	19.60		180		3.6	
		217	45.20		415		4.6	
5	Dabob Bay	218	29.80		273		3.6	
		219	21.37		196		14.5	++
		220	45.27		415		15.2	++
6	Hood Canal (central)	221	9.87		91		12.4	++
		222	111.70		1025		7.4	
		223	11.67		107		8.2	
7	Hood Canal (south)	224	5.80		53	**	8.0	
		225	2.73		25	**	9.4	
		226	14.63		134		6.5	
8	Port of Shelton	227	1.13		10	**	56.6	+++
		228	1.57		14	**	21.3	++
		229	0.99		9	**	26.4	++

Table 8. Continued.

Stratum	Location	Sample	Microtox™ EC50 mean (mg/ml)	Statistical signifi-cance	% of control	Statistical signifi-cance	HRGS as B[a]P eq (µg/g)	Statistical signifi-cance
9	Oakland Bay	230	1.73		16	**	27.0	++
		231	1.07		10	**	27.7	++
		232	2.60		24	**	14.1	++
10	Totten Inlet	233	1.57		14	**	12.7	++
		234	4.17		38	**	8.0	
		235	3.83		35	**	8.3	
11	Eld Inlet	238	0.77		7	**	16.1	++
		239	4.20		39	**	8.4	
		240	4.27		39	**	15.0	++
12	Budd Inlet	236	2.00		18	**	18.5	++
		237	1.60		15	**	11.4	++
		241	1.30		12	**	25.6	++
13	Port of Olympia	242	1.01		9	**	45.7	+++
		243	0.31	^	3	**	122.7	+++
		244	0.74		7	**	20.1	++
14	Pickering Passage/Squaxin Island	245	7.33		67	**	1.8	
		246	7.87		72		4.2	
		247	6.63		61	**	2.7	
15	Henderson Inlet	248	3.60		33	**	9.1	
		249	1.43		13	**	10.8	
		250	3.73		34	**	10.4	
16	Case Inlet	251	2.33		21	**	21.9	++
		252	7.40		68	**	20.0	++
		253	4.87		45	**	9.0	
17	Nisqually Reach	254	9.97		91		2.1	

Table 8. Continued.

Stratum	Location	Sample	Microtox™ EC50 mean (mg/ml)	Statistical signifi-cance	% of control	Statistical signifi-cance	HRGS as B[a]P eq (µg/g)	Statistical signifi-cance
		255	5.27		48	**	7.4	
		256	8.13		75		5.5	
18	Drayton Passage	257	2.80		26	**	15.7	++
		258	7.37		68	**	2.0	
		259	5.63		52	**	2.3	
19	East Anderson Island/No. Cormorant Passage	260	6.57		60	**	12.4	++
		261	5.07		46	**	9.0	
		262	7.07		65	**	5.2	
20	Carr Inlet	263	14.53		133		3.5	
		264	15.80		145		7.0	
		265	6.23		57	**	12.8	++
21	Hale Passage	266	6.63		61	**	2.0	
		267	6.80		62	**	4.1	
		268	6.43		59	**	1.6	
22	Gig Harbor	269	2.80		26	**	33.3	++
		270	0.95		9	**	31.3	++
		271	2.00		18	**	87.0	+++
23	Colvos Passage	272	29.80		273		3.9	
		273	31.47		289		2.3	
		274	28.40		261		3.7	
24	Quartermaster Harbor	275	51.07		469		5.2	
		276	0.71		7	**	29.2	++
		277	1.30		12	**	16.4	++
25	East Passage	278	18.10		166		78.9	+++
		279	3.63		33	**	24.5	++
		280	175.30		1608		1.5	

Table 8. Continued.

Stratum	Location	Sample	Microtox™ EC50 mean (mg/ml)	Statistical signifi-cance	% of control	Statistical signifi-cance	HRGS as B[a]P eq (µg/g)	Statistical signifi-cance
26	Outer Commencement Bay	281	3.77		35	**	11.8	++
		282	4.30		39	**	27.8	++
		283	11.57		106		18.8	++
		284	6.47		59	**	7.0	
27	S. E. Commencement Bay (shoreline)	285	9.07		83		19.8	++
		286	5.77		53	**	26.4	++
		287	4.67		43	**	121.7	+++
28	S. E. Commencement Bay	288	9.20		84		12.8	++
		289	11.00		101		18.2	++
		290	7.87		72		18.8	++
29	N.E. Commencement Bay	291	5.47		50	**	22.0	++
		292	4.03		37	**	28.4	++
		293	0.43	^	4	**	109.0	+++
30	Thea Foss Waterway	294	0.32	^	3	**	1994.9	+++
		295	1.37		13	**	529.1	+++
		296	1.14		10	**	355.7	+++
31	Middle Waterway	297	3.03		28	**	44.2	+++
		298	0.89		8	**	73.3	+++
		299	2.00		18	**	119.7	+++
32	Blair Waterway	300	3.27		30	**	36.7	++
		301	2.60		24	**	33.3	++
		302	4.33		40	**	19.9	++
33	Hylebos Waterway	303	0.88		8	**	176.2	+++
		304	1.23		11	**	104.8	+++
		305	0.82		7	**	73.3	+++

Table 8. Concluded.

^ = mean EC50 <0.51 mg/ml determined as the 80% lower prediction limit (LPL) with the lowest (i.e., most toxic) samples removed, but >0.06 mg/ml determined as the 90% lower prediction limit (LPL) earlier in this report

* indicates significantly different from controls ($p < 0.05$)
** indicates significantly different from controls ($p < 0.05$) and <80% of controls

++ = value >11.1 benzo[a]pyrene equivalents (μg/g sediment) determined as the 80% upper prediction limit (UPL)
+++ = value >37.1 benzo[a]pyrene equivalents (μg/g sediment) determined as the 90% upper prediction limit (UPL)

Table 9. Estimates of the spatial extent of significant responses in four independent tests performed on 100 sediment samples from southern Puget Sound. Total study area 857.68 km^2.

Toxicity test	"Toxic" area (km^2)	Percent of total area
Amphipod survival		
• Mean survival < 80% of controls	0	0
Urchin fertilization (mean fertilization < 80% of controls)		
• 100% pore water	48.9	5.7
• 50% pore water	4.7	0.5
• 25% pore water	2.2	0.3
Microbial bioluminescence		
• < 80% of controls	518.6	60.5
• < 0.51 mg/ml[A]	1.5	0.2
• <0.06 mg/ml[B]	0.0	0.0
Cytochrome P450 HRGS		
• > 11.1 µg/g[C]	329.2	38.4
• > 37.1 µg/g[D]	43.1	5.0

[A] Critical value: mean EC50 < 0.51 mg/ml (80% lower prediction limit (LPL) with lowest, i.e. most toxic, samples removed)

[B] Critical value: mean EC50 <0.06 mg/ml (90% LPL of the entire data set - NOAA surveys and northern Puget Sound data, n=1013).

[C] Critical value: > 11.1 µg/g benzo[a]pyrene equivalents/g sediment determined as the 80% upper prediction limit (UPL) following removal of 10% of the most toxic (highest) values form a database composed of NOAA data from many surveys nationwide (n=530).

[D] Critical value: >37.1 µg/g benzo[a]pyrene equivalents/g sediment determined as the 90% UPL of the entire NOAA data set (n=530).

Table 10. Spearman-rank correlation coefficients (rho, corrected for ties) for combinations of different toxicity tests performed with 100 sediment samples from southern Puget Sound.

	Amphipod survival	Significance (p)	Microbial bioluminescence	Significance (p)	Cytochrome P450 HRGS assay	Significance (p)
Amphipod survival [A]						
Microbial bioluminescence [A]	0.025	ns				
Cytochrome P450 HRGS	0.075	ns	-0.684	****		
Urchin fertilization [A]	0.147	ns	0.166	ns	-0.314	**

ns = not significant ($p>0.05$)
** $p<0.01$
**** $p<0.0001$
[A] analyses performed with control-normalized data

Table 11. Sediment types characterizing the 100 samples collected in 1999 from southern Puget Sound.

Sediment type	% Sand	% Silt-clay	% Gravel (range of data for each station type)	No. of stations with this sediment type
Sand	> 80	< 20	24.6	24
Silty sand	60-80	20 - <40	7.5	12
Mixed	20 -< 60	40 – 80	32.3	40
Silt clay	< 20	> 80	6.3	24

Table 12. Samples from the 1999 southern Puget Sound survey in which individual numerical guidelines or Washington State criteria were exceeded.

Stratum, Sample, Location	Number of ERLs exce-eded	Mean ERM Quot-ient	Number of ERMs exce-eded	Chemicals exceeding ERMs	Number of SQSs exce-eded	Chemicals exceeding SQSs	Number of CSLs exce-eded	Chemicals exceeding CSLs
1, 206, Port Ludlow	9	0.16						
1, 207, Port Ludlow	5	0.09			1	**LPAHs:** Naphthalene		
1, 208, Port Ludlow	5	0.10						
2, 209, Hood Canal (north)	0	0.09						
2, 210, Hood Canal (north)	0	0.07						
2, 211, Hood Canal (north)	1	0.07						
3, 212, Port Gamble Bay	6	0.11	1	**Metals:** Silver				
3, 213, Port Gamble Bay	3	0.07						
3, 214, Port Gamble Bay	18	0.50	4	**LPAHs:** Ace-naphthylene, Naphthalene, Phenanthrene, Total LPAH				
4, 215, Quilcene Bay	3	0.18						
4, 216, Quilcene Bay	2	0.09						
4, 217, Quilcene Bay	2	0.09						
5, 218, Dabob Bay	2	0.09						
5, 219, Dabob Bay	3	0.10						
5, 220, Dabob Bay	2	0.10						
6, 221, Hood Canal (central)	3	0.18						

Table 12. Continued.

Stratum, Sample, Location	Number of ERLs exceeded	Mean ERM Quotient	Number of ERMs exceeded	Chemicals exceeding ERMs	Number of SQSs exceeded	Chemicals exceeding SQSs	Number of CSLs exceeded	Chemicals exceeding CSLs
6, 222, Hood Canal (central)	1	0.09						
6, 223, Hood Canal (central)	3	0.11						
7, 224, Hood Canal (south)	4	0.14						
7, 225, Hood Canal (south)	4	0.13						
7, 226, Hood Canal (south)	3	0.12						
8, 227, Port of Shelton	16	0.22						
8, 228, Port of Shelton	5	0.15						
8, 229, Port of Shelton	7	0.15						
9, 230, Oakland Bay	8	0.18						
9, 231, Oakland Bay	3	0.14						
9, 232, Oakland Bay	5	0.12						
10, 233, Totten Inlet	3	0.09						
10, 234, Totten Inlet	3	0.10						
10, 235, Totten Inlet	4	0.19	1	**Metals:** Mercury	1	**Metals:** Mercury	1	**Metals:** Mercury
11, 238, Eld Inlet	3	0.12						
11, 239, Eld Inlet	3	0.10						
11, 240, Eld Inlet	4	0.11						
12, 236, Budd Inlet	3	0.12						
12, 237, Budd Inlet	3	0.11			2	**Other:** Benzoic Acid, Benzyl Alcohol	2	**Other:** Benzoic Acid, Benzyl Alcohol

Table 12. Continued.

Stratum, Sample, Location	Number of ERLs exce-eded	Mean ERM Quot-ient	Number of ERMs exce-eded	Chemicals exceeding ERMs	Number of SQSs exce-eded	Chemicals exceeding SQSs	Number of CSLs exce-eded	Chemicals exceeding CSLs
12, 241, Budd Inlet	3	0.10						
13, 242, Port of Olympia	13	0.23						
13, 243, Port of Olympia	23	0.43			2	**Other:** Benzoic Acid, Bis(2-Ethylhexyl) Phthalate	1	**Other:** Benzoic Acid
13, 244, Port of Olympia	4	0.13			1	**Other:** Phenol	1	**Other:** Phenol
14, 245, Pickering Passage/ Squaxin Island	1	0.07			1	**Other:** Benzyl Alcohol		
14, 246, Pickering Passage/ Squaxin Island	0	0.07						
14, 247, Pickering Passage/ Squaxin Island	1	0.05			1	**Other:** Benzyl Alcohol	1	**Other:** Benzyl Alcohol
15, 248, Henderson Inlet	3	0.10						
15, 249, Henderson Inlet	3	0.10						
15, 250, Henderson Inlet	2	0.10			2	**Other:** Benzoic Acid, Phenol	2	**Other:** Benzoic Acid, Phenol
16, 251, Case Inlet	1	0.09						
16, 252, Case Inlet	2	0.10						
16, 253, Case Inlet	2	0.10						
17, 254, Nisqually Reach	0	0.05						

Table 12. Continued.

Stratum, Sample, Location	Number of ERLs exceeded	Mean ERM Quotient	Number of ERMs exceeded	Chemicals exceeding ERMs	Number of SQSs exceeded	Chemicals exceeding SQSs	Number of CSLs exceeded	Chemicals exceeding CSLs
17, 255, Nisqually Reach	0	0.06						
17, 256, Nisqually Reach	0	0.06						
18, 257, Drayton Passage	1	0.08						
18, 258, Drayton Passage	0	0.05						
18, 259, Drayton Passage	0	0.05						
19, 260, East Anderson Island/No. Cormorant Passage	1	0.10			1	**Other:** Benzoic Acid	1	**Other:** Benzoic Acid
19, 261, East Anderson Island/No. Cormorant Passage	1	0.09						
19, 262, East Anderson Island/No. Cormorant Passage	0	0.09						
20, 263, Carr Inlet	0	0.08						
20, 264, Carr Inlet	4	0.20						
20, 265, Carr Inlet	3	0.13						
21, 266, Hale Passage	0	0.04			1	**Other:** Benzoic Acid	1	**Other:** Benzoic Acid
21, 267, Hale Passage	0	0.05						
21, 268, Hale Passage	0	0.07						
22, 269, Gig Harbor	0	0.08						

Table 12. Continued.

Stratum, Sample, Location	Number of ERLs exce-eded	Mean ERM Quot-ient	Number of ERMs exce-eded	Chemicals exceeding ERMs	Number of SQSs exce-eded	Chemicals exceeding SQSs	Number of CSLs exce-eded	Chemicals exceeding CSLs
22, 270, Gig Harbor	1	0.14						
22, 271, Gig Harbor	19	0.33						
23, 272, Colvos Passage	0	0.08						
23, 273, Colvos Passage	1	0.08						
23, 274, Colvos Passage	0	0.07						
24, 275, Quartermaster Harbor	0	0.05						
24, 276, Quartermaster Harbor	5	0.15						
24, 277, Quartermaster Harbor	4	0.11						
25, 278, East Passage	10	0.20						
25, 279, East Passage	5	0.14						
25, 280, East Passage	1	0.08						
26, 281, Outer Commen-cement Bay	5	0.12						
26, 282, Outer Commen-cement Bay	7	0.16						
26, 283, Outer Commen-cement Bay	4	0.14						
26, 284, Outer Commen-cement Bay		0.16						

Table 12. Continued.

Stratum, Sample, Location	Number of ERLs exceeded	Mean ERM Quotient	Number of ERMs exceeded	Chemicals exceeding ERMs	Number of SQSs exceeded	Chemicals exceeding SQSs	Number of CSLs exceeded	Chemicals exceeding CSLs
27, 285, S. E. Commencement Bay (shoreline)	3	0.12						
27, 286, S. E. Commencement Bay (shoreline)	8	0.14						
27, 287, S. E. Commencement Bay (shoreline)	20	0.53	2	LPAHs: Phenanthrene, Total LPAH				
28, 288, S. E. Commencement Bay	7	0.18						
28, 289, S. E. Commencement Bay	8	0.14						
28, 290, S. E. Commencement Bay	8	0.12						
29, 291, N.E. Commencement Bay	6	0.11						
29, 292, N.E. Commencement Bay	6	0.14						
29, 293, N.E. Commencement Bay	15	0.25						

Table 12. Continued.

Stratum, Sample, Location	Number of ERLs exce-eded	Mean ERM Quot-ient	Number of ERMs exce-eded	Chemicals exceeding ERMs	Number of SQSs exce-eded	Chemicals exceeding SQSs	Number of CSLs exce-eded	Chemicals exceeding CSLs
30, 294, Thea Foss Waterway	27	4.25	18	**Metals:** Lead; **LPAHs:** 2-Methyl-naphthalene, Ace-naphthene, Ace-naphthylene, Anthracene, Fluorene, Phenanthrene, Total LPAHs; **HPAHs:** Benzo(a) anthracene, Benzo(a) pyrene, Chrysene, Dibenzo(a,h) anthracene, Fluoranthene, Naphthalene, Pyrene, Total HPAHs, Total PAHs; **Other:** Total PCBs	11	**Metals:** Mercury; **LPAHs:** Ace-naphthene, Fluorene, Phen-anthrene; **HPAHs:** Benzo(g,h,i) perylene, Fluor-anthene, Indeno(1,2,3 -c,d)pyrene; **Other:** Dibenzo-furan, 2,4-Dimethyl-phenol, Bis(2Ethylh exyl) Phthalate, Total Aroclors	2	**Metals:** Mercury; **Other:** 2,4-Dimethyl-phenol
30, 295, Thea Foss Waterway	21	0.52	1	**LPAHs:** Total LPAHs	1	**Other:** Butylbenzyl phthalate		
30, 296, Thea Foss Waterway	21	0.55	2	**LPAHs:** Total LPAHs; **HPAHs**: Pyrene	2	**HPAHs:** Benzo(g,h,i) perylene, Indeno(1,2,3 -c,d)pyrene		
31, 297, Middle Waterway	19	0.41						
31, 298, Middle Waterway	18	0.29						

Table 12. Continued.

Stratum, Sample, Location	Number of ERLs exceeded	Mean ERM Quotient	Number of ERMs exceeded	Chemicals exceeding ERMs	Number of SQSs exceeded	Chemicals exceeding SQSs	Number of CSLs exceeded	Chemicals exceeding CSLs
31, 299, Middle Waterway	22	1.11	12	**Metals:** Copper, Mercury; **LPAHs:** Acenaphthene, Anthracene, Fluorene, Phenanthrene, Total LPAHs; **HPAHs:** Benzo(a) anthracene, Benzo(a) pyrene, Dibenzo(a,h) anthracene, Pyrene, Total HPAHs	16	**Metals:** Arsenic, Cooper, Mercury; **LPAHs:** Acenaphthene, Fluorene, Phenanthrene, Total LPAHs; **HPAHs:** Benzo(a) anthracene, Benzo(a) pyrene, Benzo(g,h,i) perylene, Chrysene, Dibenzo (a,h) anthracene, Fluoranthene, Indeno(1,2,3 -c,d)pyrene, Total HPAHs; **Other:** Dibenzofuran	4	**Metals:** Cooper, Mercury; **LPAHs:** Acenaphthene; HPAHs: Dibenzo (a,h) anthracene
32, 300, Blair Waterway	4	0.13						
32, 301, Blair Waterway	3	0.13						
32, 302, Blair Waterway	2	0.16						
33, 303, Hylebos Waterway	24	2.05	1	**Other:** Total PCBs	2	**Other:** Hexachlorobenzene, Total Aroclors		

Table 12. Concluded.

Stratum, Sample, Location	Number of ERLs exceeded	Mean ERM Quotient	Number of ERMs exceeded	Chemicals exceeding ERMs	Number of SQSs exceeded	Chemicals exceeding SQSs	Number of CSLs exceeded	Chemicals exceeding CSLs
33, 304, Hylebos Waterway	12	0.58			3	**Other:** Hexachlorobenzene, Phenol, Total Aroclors		
33, 305, Hylebos Waterway	19	1.08			1	**Other:** Hexachlorobenzene		

Table 13. Number of 1999 southern Puget Sound samples exceeding individual numerical guidelines and estimated spatial extent of chemical contamination (expressed as percentage of total area) relative to each guideline. Total sampling area = 857.68 km^2.

Compound	≥ ERM[a]			> SQS[b]			> CSL[b]		
	No.	% of Total Area	Sample Number and Location	No.	% of Total Area	Sample Number and Location	No.	% of Total Area	Sample Number and Location
Trace Metals									
Arsenic	0	0.00		1	0.002	Middle Waterway: 299	0	0.00	
Cadmium	0	0.00		0	0.00		0	0.00	
Chromium	0	0.00		0	0.00		0	0.00	
Copper	1	0.002	Middle Waterway: 299	1	0.002	Middle Waterway: 299	1	0.002	Middle Waterway: 299
Lead	1	0.01	Thea Foss Waterway: 294	0	0.00		0	0.00	
Mercury	3	0.68	Totten Inlet: 235; Thea Foss Waterway: 294; Middle Waterway: 299	3	0.68	Totten Inlet: 235; Thea Foss Waterway: 294; Middle Waterway: 299	3	0.68	Totten Inlet: 235; Thea Foss Waterway: 294; Middle Waterway: 299
Nickel	5	8.20	Quilcene Bay: 215; Hood Canal: 221, 224, 225, 226	0	0.00		0	0.00	
Silver	1	0.16	Port Gamble Bay: 212	0	0.00		0	0.00	
Zinc	0	0.00		0	0.00		0	0.00	
Total for any individual trace metals (excluding Nickel)	4	0.84	Port Gamble Bay: 212; Totten Inlet: 235; Thea Foss Waterway: 294; Middle Waterway; 299	3	0.68	Totten Inlet: 235; Thea Foss Waterway: 294; Middle Waterway; 299	3	0.68	Totten Inlet: 235; Thea Foss Waterway: 294; Middle Waterway; 299
Organic Compounds									
LPAH									
2-Methylnaphthalene	1	0.01	Thea Foss Waterway: 294	0	0.00		0	0.00	
Acenaphthene	2	0.02	Thea Foss Waterway: 294; Middle Waterway: 299	2	0.02	Thea Foss Waterway: 294; Middle Waterway: 299	1	0.01	Middle Waterway: 299
Acenaphthylene	2	0.18	Port Gamble Bay: 214; Thea Foss Waterway: 294	0	0.00		0	0.00	
Anthracene	2	0.02	Thea Foss Waterway: 294; Middle Waterway: 299	0	0.00		0	0.00	
Fluorene	2	0.02	Thea Foss Waterway: 294; Middle Waterway: 299	2	0.02	Thea Foss Waterway: 294; Middle Waterway: 299	0	0.00	

Table 13. Continued.

Compound	≥ ERM[a] No.	≥ ERM[a] % of Total Area	≥ ERM[a] Sample Number and Location	> SQS[b] No.	> SQS[b] % of Total Area	> SQS[b] Sample Number and Location	> CSL[b] No.	> CSL[b] % of Total Area	> CSL[b] Sample Number and Location
Naphthalene	2	0.18	Port Gamble Bay: 214; Thea Foss Waterway: 294	1	0.18	Port Ludlow: 207	0	0.00	
Phenanthrene	4	0.27	Port Gamble Bay: 214; Commencement Bay 287; Thea Foss Waterway 294; Middle Waterway: 299	2	0.02	Thea Foss Waterway: 294; Middle Waterway: 299	0	0.00	
Total for any individual LPAH	4	0.27	Port Gamble: 214; Commencement Bay: 287; Thea Foss Waterway: 294; Middle Waterway: 299	3	0.20	Port Ludlow: 207; Thea Foss Waterway: 294; Middle Waterway: 299	1	0.02	Middle Waterway: 299
Sum of LPAHs:									
Sum of 6 LPAH (WA Ch. 173-204 RCW)	NA	NA		1	0.002	Middle Waterway: 299	0	0.00	
Sum of 7 LPAH (Long et al., 1995)	6	0.30	Port Gamble Bay: 214; Commencement Bay 287; Thea Foss Waterway: 294, 295, 296; Middle Waterway: 299	NA	NA		NA	NA	
<u>**HPAH**</u>									
Benzo(a)anthracene	2	0.02	Thea Foss Waterway: 294; Middle Waterway: 299	1	0.002	Middle Waterway: 299	0	0.00	
Benzo(a)pyrene	2	0.02	Thea Foss Waterway: 294; Middle Waterway: 299	1	0.002	Middle Waterway: 299	0	0.00	
Benzo(g,h,i)perylene	NA	NA		3	0.03	Thea Foss Waterway: 294, 296; Middle Waterway: 299	0	0.00	
Chrysene	1	0.01	Thea Foss Waterway: 294	1	0.002	Middle Waterway: 299	0	0.00	
Dibenzo(a,h)anthracene	2	0.02	Thea Foss Waterway: 294; Middle Waterway: 299	1	0.002	Middle Waterway: 299	1	0.002	Middle Waterway: 299
Fluoranthene	1	0.01	Thea Foss Waterway: 294	2	0.02	Thea Foss Waterway: 294; Middle Waterway: 299	0	0.00	
Indeno(1,2,3-c,d)pyrene	NA	NA		0	0.00		0	0.00	

Table 13. Continued.

Compound	≥ ERM[a]			> SQS[b]			> CSL[b]		
	No.	% of Total Area	Sample Number and Location	No.	% of Total Area	Sample Number and Location	No.	% of Total Area	Sample Number and Location
Pyrene	3	0.03	Thea Foss Waterway: 294, 296; Middle Waterway: 299	0	0.00		0	0.00	
Total Benzofluoranthenes	NA	NA		0	0.00		0	0.00	
Total for any individual HPAH	3	0.03	Thea Foss Waterway: 294, 296; Middle Waterway: 299	3	0.03	Thea Foss Waterway: 294, 296; Middle Waterway: 299	1	0.002	Middle Waterway: 299
Sum of HPAHs:									
Sum of 9 HPAH (WA Ch. 173-204 RCW)	NA	NA		1	0.002	Middle Waterway: 299	0	0.00	
Sum of 6 HPAH (Long et al., 1995)	2	0.02	Thea Foss Waterway: 294; Middle Waterway: 299	NA	NA		NA	NA	
Total for any individual PAH	6	0.30	Port Gamble Bay: 214; Commencement Bay: 287; Thea Foss Waterway: 294, 295, 296; Middle Waterway: 299	4	0.23	Port Ludlow: 207; Thea Foss Waterway 294, 296; Middle Waterway: 299	1	0.002	Middle Waterway: 299
Sum of 13 PAHs (Long et al., 1995)	1	0.01	Thea Foss Waterway: 294	NA	NA		NA	NA	
<u>**Phenols**</u>									
2,4-Dimethylphenol	NA	NA		6	13.52	Hood Canal: 221, 223, 224; Budd Inlet: 236; Carr Inlet: 264; Thea Foss Waterway: 294	6	13.52	Hood Canal: 221, 223, 224; Budd Inlet: 236; Carr Inlet: 264; Thea Foss Waterway: 294
>QL only	NA	NA		1	0.01	Thea Foss Waterway: 294	1	0.01	Thea Foss Waterway: 294
2-Methylphenol	NA	NA		0	0.00		0	0.00	
4-Methylphenol	NA	NA		0	0.00		0	0.00	
Pentachlorophenol	NA	NA		0	0.00		0	0.00	
Phenol	NA	NA		9	5.35	Totten Inlet: 233, 234, 235; Budd Inlet: 241, Port of Olympia: 242, 244; Henderson Inlet: 250; Case Inlet 251; Hylebos Waterway: 304	3	0.25	Port of Olympia: 242, 244, Henderson Inlet: 250

Table 13. Continued.

Compound	≥ ERM[a]			> SQS[b]			> CSL[b]		
	No.	% of Total Area	Sample Number and Location	No.	% of Total Area	Sample Number and Location	No.	% of Total Area	Sample Number and Location
>QL only	NA	NA		3	0.25	Port of Olympia: 244; Henderson Inlet: 250; Hylebos Waterway: 304	2	0.22	Port of Olympia: 244; Henderson Inlet: 250
Total for any individual phenols:	NA	NA		15	18.87		9	13.78	Hood Canal: 221, 223, 224; Budd Inlet: 236; Port of Olympia: 242, 244; Henderson Inlet 250; Carr Inlet: 264; Thea Foss Waterway: 294
>QL only	NA	NA		4	0.26	Port of Olympia: 244; Henderson Inlet: 250; Thea Foss Waterway 294; Hylebos Waterway: 304	3	0.24	Port of Olympia: 244; Henderson Inlet 250; Thea Foss Waterway: 294
Phthalate Esters									
Bis (2-Ethylhexyl) Phthalate	NA	NA		2	0.05	Port of Olympia: 243; Thea Foss Waterway: 294	0	0.00	
>QL only	NA	NA		2	0.05	Port of Olympia: 243; Thea Foss Waterway: 294	0	0.00	
Butylbenzylphthalate	NA	NA		3	3.07	Hale Passage: 268; East Passage: 280; Thea Foss Waterway: 295	0	0.00	
>QL only	NA	NA		1	0.01	Thea Foss Waterway: 295	0	0.00	
Diethylphthalate	NA	NA		0	0.00		0	0.00	
Dimethylphthalate	NA	NA		0	0.00		0	0.00	
Di-N-Butyl Phthalate	NA	NA		0	0.00		0	0.00	
Di-N-Octyl Phthalate	NA	NA		0	0.00		0	0.00	
Total for any individual phthalate esters	NA	NA		5	3.12	Port of Olympia: 243; Hale Passage: 268; East Passage: 280; Thea Foss Waterway: 294, 295	0	0.00	
>QL only	NA	NA		1	0.01	Thea Foss Waterway: 295	0	0.00	
Chlorinated Pesticide and PCBs									
4,4'-DDE	0	0.00		NA	NA		NA	NA	

Table 13. Continued.

Compound	≥ ERM[a]			> SQS[b]			> CSL[b]		
	No.	% of Total Area	Sample Number and Location	No.	% of Total Area	Sample Number and Location	No.	% of Total Area	Sample Number and Location
Total DDT	2	0.04	Thea Foss Waterway: 294; Hylebos Waterway: 303	NA	NA		NA	NA	
>QL only	0	0.00		NA	NA		NA	NA	
Total PCB:									
Total Aroclors (WA Ch. 173-204 RCW)	NA	NA		15	42.83		1	2.63	East Passage: 280
>QL only				3	0.07	Thea Foss Waterway: 294; Hylebos Waterway: 303, 304	0	0.00	
Total congeners (Long et al., 1995):	2	0.04	Thea Foss Waterway: 294; Hylebos Waterway: 303	NA	NA		NA	NA	
<u>**Miscellaneous Compounds**</u>									
1,2-Dichlorobenzene	NA	NA		6	7.50	Drayton Passage: 258; Hale Passage: 266, 268; Colvos Passage 273, 274; East Passage: 280	6	7.50	Drayton Passage: 258; Hale Passage: 266, 268; Colvos Passage 273, 274; East Passage: 280
>QL only				0	0.00		0	0.00	
1,2,4-Trichlorobenzene	NA	NA		28	43.81		12	16.33	Hood Canal: 211; Pickering Passage 245, 247; Nisqually Reach: 254; Draton Passage: 258; Hale Passage 266, 267, 268; Colvos Passage: 273, 274; Quartermaster Harbor: 275; East Passage: 280
>QL only				0	0.00		0	0.00	
1,4-Dichlorobenzene	NA	NA		3	3.48	Hale Passage: 266, 268; East Passage: 280	0	0.00	
>QL only				0	0.00		0	0.00	
Benzoic Acid	NA	NA		14	14.71		14	14.71	

Table 13. Continued.

Compound	≥ ERM[a] No.	≥ ERM[a] % of Total Area	≥ ERM[a] Sample Number and Location	> SQS[b] No.	> SQS[b] % of Total Area	> SQS[b] Sample Number and Location	> CSL[b] No.	> CSL[b] % of Total Area	> CSL[b] Sample Number and Location
>QL only				5	3.21	Budd Inlet: 237; Port of Olympia: 243; Henderson Inlet 250; E. Anderson Island: 260; Hale Passage: 266	5	3.21	Budd Inlet: 237; Port of Olympia: 243; Henderson Inlet 250; E. Anderson Island: 260; Hale Passage: 266
Benzyl Alcohol	NA	NA		12	17.96	Hood Canal: 221, 223, 224, 226; Budd Inlet: 236, 237; Port of Olympia: 242, 244; Pickering Passage: 245, 247; Carr Inlet 264; Thea Foss Waterway: 294	8	15.38	Hood Canal: 221, 223, 224; Budd Inlet: 236, 237; Pickering Passage: 247; Carr Inlet 264; Thea Foss Waterway: 294
>QL only				3	3.09	Budd Inlet: 237; Pickering Passage: 245, 247;	2	1.86	Budd Inlet: 237; Pickering Passage: 247
Dibenzofuran	NA	NA		1	0.002	Middle Waterway: 299	0	0.00	
Hexachlorobenzene	NA	NA		6	3.56	Pickering Passage: 266; Hale Passage: 268; East Passage: 280; Hylebos Waterway: 303, 304, 305	0	0.00	
>QL only				3	0.08	Hylebos Waterway: 303, 304, 305	0	0.00	
Hexachlorobutadiene	NA	NA		3	3.48	Hale Passage; 266, 268; East Passage: 280	2	0.00	Hale Passage: 268; East Passage: 280
>QL only				0	0.00		0	0.00	
N-Nitrosodiphenylamine	NA	NA		0	0.00		0	0.00	

Table 13. Concluded.

Compound	≥ ERM[a]			> SQS[b]			> CSL[b]		
	No.	% of Total Area	Sample Number and Location	No.	% of Total Area	Sample Number and Location	No.	% of Total Area	Sample Number and Location
***Total for all individual coumpounds (excluding Nickel)**	9	1.15	Port Gamble: 212, 214; Totten Inlet: 235; Commencement Bay: 287; Thea Foss Waterway: 294, 295, 296; Middle Waterway: 299; Hylebos Waterway: 303, 304, 305	61	70.69		34	40.79	
>QL only				17	7.30	Port Ludlow: 207; Totten Inlet: 235; Budd Inlet: 237; Port of Olympia: 243, 244Pickering Passage: 245; South Squaxin Island: 247; Henderson Inlet: 250; East of Anderson Island: 260; Hale Passage: 266; Thea Foss Waterway: 294, 295, 296; Middle Waterway: 299; Hylebos Waterway: 303, 304, 305	10	5.15	Totten Inlet: 235; Budd Inlet: 237; Port of Olympia: 243, 244; Pickering Passage: 247; Henderson Inlet: 250; East Anderson Island: 260; Hale Passage: 266; Thea Foss Waterway: 294; Middle Waterway: 299

[a] ERM = effects range median (Long et al., 1995)

[b] SQS = sediment quality standard, CSL = cleanup screening levels (Washington State Sediment Management Standards - Ch. 173-204 WAC)

* = calculation includes all values which exceed guidelines or standards, including those that were at or below the quantitation limits reported by Manchester

NA = no guideline or standard available

Table 14. Spearman-rank correlation coefficients (rho, corrected for ties) and significance levels (p) for results of four toxicity tests and concentrations of trace metals, chlorinated organic hydrocarbons, and total PAHs, normalized to their respective ERM, SQS, CSL values for all 1999 southern Puget Sound sites (n=100).

Chemical	Amphipod survival	(p)	Urchin fertilization	(p)	Microbial bioluminescence	(p)	Cytochrome P450 HRGS	(p)
ERM values								
mean ERM quotients for 9 trace metals	0.002	ns	-0.133	ns	-0.405	***	0.459	****
mean ERM quotients for 13 polynuclear aromatic hydrocarbons	0.068	ns	-0.382	**	-0.537	****	0.816	****
mean ERM quotients for 25 substances	0.058	ns	-0.300	*	-0.536	****	0.805	****
SQS values								
mean SQS quotients for 8 trace metals	-0.013	ns	-0.178	ns	-0.520	****	0.633	****
mean SQS quotients for 6 low molecular weight polynuclear aromatic hydrocarbons	0.055	ns	-0.314	*	-0.315	*	0.585	****
mean SQS quotients for 9 high molecular weight polynuclear aromatic hydrocarbons	-0.038	ns	-0.362	**	-0.329	**	0.596	****
mean SQS quotients for 15 polynuclear aromatic hydrocarbons	0.011	ns	-0.338	**	-0.341	**	0.609	****
CSL values								
mean CSL quotients for 8 trace metals	-0.006	ns	-0.173	ns	-0.514	****	0.627	****
mean CSL quotients for 6 low molecular weight polynuclear aromatic hydrocarbons	0.064	ns	-0.305	*	-0.308	*	0.582	****
mean CSL quotients for 9 high molecular weight polynuclear aromatic hydrocarbons	-0.038	ns	-0.354	**	-0.320	*	0.592	****
mean CSL quotients for 15 polynuclear aromatic hydrocarbons	0.014	ns	-0.332	**	-0.343	**	0.609	****

ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
**** = $p \leq 0.0001$

Table 15. Spearman-rank correlation coefficients (rho, corrected for ties) and significance levels (p) for results of four toxicity tests and concentrations of partial digestion metals in sediments for all 1999 southern Puget Sound sites (n=100).

Chemical	Amphipod survival (p)	Urchin fertilization (p)	Microbial bioluminescence (p)	Cytochrome P450 HRGS (p)
Aluminum	0.139 ns	-0.034 ns	-0.222 ns	0.276 ns
Antimony	-0.224 ns	0.132 ns	-0.319 ns	0.623 ns
Arsenic	-0.138 ns	-0.098 ns	-0.418 **	0.562 ****
Barium	0.081 ns	-0.131 ns	-0.231 ns	0.590 ****
Beryllium	0.138 ns	0 ns	-0.165 ns	0.179 ns
Cadmium	-0.128 ns	-0.05 ns	-0.394 ns	0.124 ns
Calcium	0.036 ns	0.046 ns	-0.283 ns	0.264 ns
Chromium	0.216 ns	-0.001 ns	-0.201 ns	0.133 ns
Cobalt	0.182 ns	-0.013 ns	0.049 ns	0.026 ns
Copper	0.003 ns	-0.157 ns	-0.418 **	0.591 ****
Iron	0.207 ns	-0.013 ns	-0.170 ns	0.249 ns
Lead	-0.102 ns	-0.309 ns	-0.485 ****	0.724 ****
Magnesium	0.216 ns	0.034 ns	-0.098 ns	0.122 ns
Manganese	0.105 ns	0.015 ns	0.368 *	-0.378 *
Mercury	0.021 ns	-0.291 ns	-0.499 ****	0.714 ****
Nickel	0.241 ns	0.050 ns	0.022 ns	-0.084 ns
Potassium	0.054 ns	-0.015 ns	-0.218 ns	0.331 ns
Selenium	0.020 ns	-0.059 ns	-0.112 ns	-0.040 ns
Silver	-0.304 ns	-0.088 ns	-0.469 **	0.408 *
Sodium	0.101 ns	-0.044 ns	-0.245 ns	0.351 ns
Thallium	-0.125 ns	-0.006 ns	-0.165 ns	0.002 ns
Vanadium	0.075 ns	-0.031 ns	-0.076 ns	0.282 ns
Zinc	0.025 ns	-0.129 ns	-0.387 *	0.510 ****

ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
**** = $p \leq 0.0001$

Table 16. Spearman-rank correlation coefficients (rho, corrected for ties) and significance levels (p) for results of four toxicity tests and concentrations of total digestion metals in sediments for all 1999 southern Puget Sound sites (n=100).

Chemical	Amphipod survival (p)	Urchin fertilization (p)	Microbial bioluminescence (p)	Cytochrome P450 HRGS (p)
Aluminum	0.031 ns	-0.101 ns	-0.294 ns	0.562 ****
Antimony	-0.005 ns	-0.132 ns	-0.113 ns	0.488 *
Arsenic	-0.150 ns	-0.112 ns	-0.437 ***	0.553 ****
Barium	0.028 ns	-0.114 ns	-0.242 ns	0.343 ns
Beryllium	0.210 ns	0.408 ns	0.502 *	-0.449 ns
Cadmium	-0.002 ns	-0.061 ns	-0.646 ****	0.404 **
Calcium	-0.041 ns	-0.031 ns	-0.346 ns	0.499 ****
Chromium	0.193 ns	0.094 ns	-0.106 ns	0.065 ns
Cobalt	0.023 ns	0.030 ns	0.061 ns	0.100 ns
Copper	-0.060 ns	-0.103 ns	-0.360 ns	0.501 ***
Iron	0.124 ns	-0.007 ns	-0.165 ns	0.310 ns
Lead	-0.124 ns	-0.295 ns	-0.437 ***	0.698 ****
Magnesium	0.231 ns	-0.020 ns	-0.142 ns	0.323 ns
Manganese	-0.003 ns	0.024 ns	0.390 *	-0.302 ns
Nickel	0.118 ns	0.085 ns	0.009 ns	-0.165 ns
Potassium	-0.064 ns	-0.035 ns	0.065 ns	0.348 ns
Selenium	-0.042 ns	0.021 ns	-0.015 ns	-0.301 ns
Silver	0.042 ns	-0.046 ns	-0.338 ns	0.328 ns
Sodium	0.040 ns	0.002 ns	-0.203 ns	0.305 ns
Thallium	-0.048 ns	0.012 ns	-0.379 ns	0.295 ns
Vanadium	0.136 ns	0.066 ns	-0.037 ns	0.232 ns
Zinc	0.005 ns	-0.157 ns	-0.387 *	0.574 ****
Silicon	0.076 ns	0.170 ns	0.275 ns	-0.403 **
Tin	0.031 ns	-0.254 ns	-0.558 ****	0.782 ****

ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
**** = $p \leq 0.0001$

Table 17. Spearman-rank correlation coefficients (rho, corrected for ties) and significance levels (p) for results of four toxicity tests and concentrations of Low Molecular Weight Polynuclear Aromatic Hydrocarbons (LPAH) in sediments for all 1999 southern Puget Sound sites (n=100).

Chemical	Amphipod survival	(p)	Urchin fertilization	(p)	Microbial bioluminescence	(p)	Cytochrome P450 HRGS	(p)
1,6,7-Trimethylnaphthalene	0.045	ns	-0.313	ns	-0.358	*	0.778	****
1-Methylnaphthalene	0.102	ns	-0.288	ns	-0.402	**	0.807	****
1-Methylphenanthrene	0.073	ns	-0.319	ns	-0.401	**	0.837	****
2,6-Dimethylnaphthalene	0.064	ns	-0.204	ns	-0.410	**	0.743	****
2-Methylnaphthalene	0.121	ns	-0.346	ns	-0.420	**	0.823	****
2-Methylphenanthrene	0.089	ns	-0.329	ns	-0.441	***	0.872	****
Acenaphthene	0.012	ns	-0.364	ns	-0.549	****	0.796	****
Acenaphthylene	0.137	ns	-0.269	ns	-0.601	****	0.820	****
Anthracene	0.050	ns	-0.322	ns	-0.596	****	0.880	****
Biphenyl	0.048	ns	-0.400	*	-0.428	**	0.726	****
Dibenzothiophene	0.040	ns	-0.313	ns	-0.490	****	0.893	****
Fluorene	0.114	ns	-0.333	ns	-0.524	****	0.870	****
Naphthalene	0.119	ns	-0.280	ns	-0.565	****	0.763	****
Phenanthrene	0.110	ns	-0.307	ns	-0.561	****	0.880	****
Retene	0.052	ns	-0.367	*	-0.443	***	0.794	****
Sum of 6 LPAH^	0.070	ns	-0.315	ns	-0.347	ns	0.614	****
Sum of 7 LPAH^^	0.117	ns	-0.299	ns	-0.562	****	0.863	****
Total LPAH	0.084	ns	-0.332	ns	-0.530	****	0.860	****

^6 LPAH = defined by WA Ch. 173-204 RCW; Acenaphthene, Acenaphthylene, Anthracene, Fluorene, Naphthalene, Phenanthrene, carbon normalized.
^^7LPAH = defined by Long et. Al., 1995; Acenaphthene, Acenaphthylene, Anthracene, Fluorene, 2-Methylnaphthalene, Naphthalene, Phenanthrene
ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
**** = $p \leq 0.0001$

Table 18. Spearman-rank correlation coefficients (rho, corrected for ties) and significance levels (p) for results of four toxicity tests and concentrations of High Molecular Weight Polynuclear Aromatic Hydrocarbons (HPAH) in sediments for all 1999 southern Puget Sound sites (n=100).

Chemical	Amphipod (p) survival	Urchin (p) fertilization	Microbial (p) bioluminescence	Cytochrome (p) P450 HRGS
Benzo(a)anthracene	0.051 ns	-0.329 ns	-0.581 ****	0.920 ****
Benzo(a)pyrene	0.067 ns	-0.315 ns	-0.596 ****	0.925 ****
Benzo(b)fluoranthene	0.059 ns	-0.252 ns	-0.545 ****	0.841 ****
Benzo(e)pyrene	0.044 ns	-0.332 ns	-0.611 ****	0.933 ****
Benzo(g,h,i)perylene	0.086 ns	-0.372 *	-0.600 ****	0.914 ****
Benzo(k)fluoranthene	0.022 ns	-0.363 *	-0.481 ***	0.835 ****
Chrysene	0.044 ns	-0.335 ns	-0.592 ****	0.923 ****
Dibenzo(a,h)anthracene	0.128 ns	-0.357 ns	-0.525 ****	0.886 ****
Fluoranthene	0.052 ns	-0.312 ns	-0.660 ****	0.906 ****
Indeno(1,2,3-c,d)pyrene	0.031 ns	-0.325 ns	-0.540 ****	0.906 ****
Perylene	0.077 ns	-0.290 ns	-0.460 ***	0.841 ****
Pyrene	0.044 ns	-0.315 ns	-0.672 ****	0.912 ****
sum of 6 HPAH^	0.047 ns	-0.325 ns	-0.643 ****	0.925 ****
sum of 9 HPAH^^	-0.029 ns	-0.371 *	-0.384 *	0.637 ****
Total HPAH	0.050 ns	-0.332 ns	-0.616 ****	0.927 ****
sum of 13 PAH^^^	0.076 ns	-0.306 ns	-0.611 ****	0.899 ****
sum of 15 PAH^^^^	0.003 ns	-0.351 ns	-0.381 *	0.639 ****
Total all PAH	0.062 ns	-0.327 ns	-0.572 ****	0.912 ****

^6HPAH = defined by Long et. al., 1995; Benzo(a)anthracene, Benzo(a)pyrene, Chrysene, Dibenzo(a,h)anthracene, Fluoranthene, Pyrene
^^9HPAH = defined by WA Ch. 173-204 RCW; Benzo(a)anthracene, Benzo(a)pyrene, Indeno(1,2,3,-c,d)pyrene, Benzo(g,h,I)perylene, Chrysene, Dibenzo(a,h)anthracene, Fluoranthene, Pyrene, Total Benzofluoranthenes, carbon normalized
^^^13PAH = 7LPAH and 6HPAH
^^^^15PAH= 6LPAH and A11HPAH
ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
**** = $p \leq 0.0001$

Table 19. Spearman-rank correlation coefficients (rho, corrected for ties) and significance levels (p) for results of four toxicity tests and concentrations of organotins and organic chemicals in sediments for all 1999 southern Puget Sound sites (n=100).

Chemical	Amphipod survival (p)	Urchin fertilization (p)	Microbial bioluminescence (p)	Cytochrome P450 HRGS (p)
Organotins				
Dibutyltin Dichloride	-0.117 ns	-0.329 ns	-0.182 ns	0.592 ns
Monobutyltin Trichloride	-0.012 ns	-0.321 ns	-0.047 ns	0.392 ns
Tributyltin Chloride	-0.097 ns	-0.144 ns	-0.155 ns	0.712 *
Phenols				
2-Methylphenol	0.235 ns	0.121 ns	-0.453 ns	0.218 ns
4-Methylphenol	0.159 ns	-0.243 ns	-0.452 ns	0.553 *
Pentachlorophenol	0.770 ns	-0.745 ns	-0.345 ns	-0.145 ns
Phenol	0.459 ns	-0.250 ns	-0.650 ns	0.273 ns
Miscellaneous				
1,4-Dichlorobenzene	0.101 ns	-0.580 ns	-0.425 ns	0.668 ns
9(H)Carbazole	0.042 ns	-0.349 ns	-0.555 ****	0.885 ****
Benzoic Acid	0.050 ns	-0.402 ns	-0.264 ns	0.134 ns
Benzyl Alcohol	-0.268 ns	0.477 ns	-0.383 ns	-0.317 ns
Bis(2-Ethylhexyl) Phthalate	-0.179 ns	-0.607 ns	-0.929 ns	0.857 ns
Butylbenzylphthalate	0.100 ns	0.500 ns	-0.900 ns	0.900 ns
Dibenzofuran	0.086 ns	-0.333 ns	-0.599 ****	0.863 ****
Diethylphthalate	0.087 ns	-0.543 ns	-0.771 ns	0.928 ns
Dimethylphthalate	-0.293 ns	-0.530 ns	0.092 ns	0.812 ns
Hexachlorobenzene	-0.328 ns	-0.022 ns	-0.376 ns	0.275 ns
Hexachlorobutadiene	0.359 ns	0.667 ns	0.051 ns	0.154 ns

ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
**** = $p \leq 0.0001$

Table 20. Spearman-rank correlation coefficients (rho, corrected for ties) and significance levels (p) for results of four toxicity tests and concentrations of DDT and PCB chemicals in sediments for all 1999 southern Puget Sound sites (n=100).

Chemical	Amphipod survival	(p)	Urchin fertilization	(p)	Microbial bioluminescence	(p)	Cytochrome P450 HRGS	(p)
4,4'-DDD	-0.114	ns	-0.494	ns	-0.409	ns	0.691	ns
4,4'-DDE	-0.273	ns	-0.350	ns	-0.709	ns	0.770	ns
4,4'-DDT	0.319	ns	-0.431	ns	-0.058	ns	0.667	ns
Total DDT	-0.291	ns	-0.414	ns	-0.412	ns	0.571	ns
PCB Aroclor 1248	-0.357	ns	-0.095	ns	-0.643	ns	0.857	ns
PCB Aroclor 1254	-0.036	ns	-0.047	ns	-0.363	ns	0.733	***
PCB Aroclor 1260	-0.040	ns	0.046	ns	-0.594	ns	0.686	ns
PCB Aroclor 1268	0.400	ns	-0.600	ns	-0.400	ns	0.600	ns
Total PCB aroclors	-0.249	ns	0.159	ns	-0.215	ns	0.711	***
PCB Congener 18	0.500	ns	-0.500	ns	-0.500	ns	-0.500	ns
PCB Congener 28	-0.024	ns	0.214	ns	-0.515	ns	0.738	ns
PCB Congener 44	0.500	ns	-0.683	ns	-0.533	ns	0.550	ns
PCB Congener 52	0.097	ns	-0.200	ns	-0.505	ns	0.609	ns
PCB Congener 66	0.109	ns	-0.441	ns	-0.335	ns	0.433	ns
PCB Congener 101	0.068	ns	-0.098	ns	-0.317	ns	0.720	***
PCB Congener 105	0.335	ns	-0.192	ns	-0.393	ns	0.653	ns
PCB Congener 118	-0.187	ns	-0.124	ns	-0.393	ns	0.698	*
PCB Congener 128	0.285	ns	-0.097	ns	-0.236	ns	0.863	ns
PCB Congener 138	-0.086	ns	-0.072	ns	-0.419	ns	0.645	**
PCB Congener 153	-0.102	ns	-0.160	ns	-0.449	ns	0.607	**
PCB Congener 170	0.245	ns	-0.014	ns	-0.056	ns	0.655	ns
PCB Congener 180	-0.063	ns	0.144	ns	-0.464	ns	0.799	**
PCB Congener 187	0.118	ns	0.062	ns	-0.428	ns	0.791	*
PCB Congener 195	-0.200	ns	-0.949	ns	-0.400	ns	0.400	ns
PCB Congener 206	-0.123	ns	-0.018	ns	-0.228	ns	0.330	ns
Total PCB congeners	-0.107	ns	-0.103	ns	-0.516	ns	0.712	****
Total HCH	-0.135	ns	-0.176	ns	-0.528	*	0.734	****

ns = p > 0.05
* = p ≤ 0.05
** = p ≤ 0.01
*** = p ≤ 0.001
**** = p ≤ 0.0001

Table 21. Total abundance, major taxa abundance, and major taxa percent abundance for the 1999 southern Puget Sound sampling stations.

Stratum	Sample	Total Abundance	Annelida	Annelida % of total abundance	Arthropoda	Arthropoda % of total abundance	Mollusca	Mollusca % of total abundance	Echino-dermata	Echinodermata % of total abundance	Misc. Taxa	Misc. Taxa % of total abundance
1	206	688	595	86.48	1	0.15	90	13.08	0	0.00	2	0.29
Port Ludlow	207	953	687	72.09	115	12.07	148	15.53	0	0.00	3	0.31
	208	1574	645	40.98	731	46.44	198	12.58	0	0.00	0	0.00
2	209	408	87	21.32	221	54.17	87	21.32	4	0.98	9	2.21
Hood Canal (north)	210	517	127	24.56	134	25.92	210	40.62	10	1.93	36	6.96
	211	587	198	33.73	257	43.78	107	18.23	2	0.34	23	3.92
3	212	1966	1764	89.73	119	6.05	69	3.51	7	0.36	7	0.36
Port Gamble Bay	213	3476	3202	92.12	143	4.11	107	3.08	10	0.29	14	0.40
	214	939	781	83.17	16	1.70	138	14.70	4	0.43	0	0.00
4	215	753	405	53.78	64	8.50	269	35.72	7	0.93	8	1.06
Quilcene Bay	216	744	344	46.24	56	7.53	325	43.68	6	0.81	13	1.75
	217	892	361	40.47	41	4.60	427	47.87	2	0.22	61	6.84
5	218	281	147	52.31	4	1.42	127	45.20	0	0.00	3	1.07
Dabob Bay	219	47	25	53.19	10	21.28	11	23.40	1	2.13	0	0.00
	220	26	12	46.15	5	19.23	7	26.92	1	3.85	1	3.85
6	221	100	64	64.00	8	8.00	24	24.00	0	0.00	4	4.00
Hood Canal (central)	222	219	82	37.44	104	47.49	30	13.70	0	0.00	3	1.37
	223	69	45	65.22	6	8.70	5	7.25	6	8.70	7	10.14
7	224	139	124	89.21	2	1.44	4	2.88	7	5.04	2	1.44
Hood Canal (south)	225	144	134	93.06	0	0.00	7	4.86	0	0.00	3	2.08
	226	286	205	71.68	28	9.79	48	16.78	0	0.00	5	1.75
8	227	299	225	75.25	21	7.02	48	16.05	5	1.67	0	0.00
Port of Shelton	228	237	156	65.82	19	8.02	59	24.89	0	0.00	3	1.27
	229	269	131	48.70	96	35.69	40	14.87	0	0.00	2	0.74

Table 21. Continued.

Stratum	Sample	Total Abundance	Annelida	Annelida % of total abundance	Arthropoda	Arthropoda % of total abundance	Mollusca	Mollusca % of total abundance	Echino-dermata	Echinodermata % of total abundance	Misc. Taxa	Misc. Taxa % of total abundance
9	230	297	31	10.44	210	70.71	49	16.50	1	0.34	6	2.02
Oakland Bay	231	89	29	32.58	11	12.36	40	44.94	0	0.00	9	10.11
	232	82	30	36.59	15	18.29	29	35.37	5	6.10	3	3.66
10	233	212	132	62.26	44	20.75	20	9.43	14	6.60	2	0.94
Totten Inlet	234	116	98	84.48	8	6.90	7	6.03	0	0.00	3	2.59
	235	259	121	46.72	39	15.06	32	12.36	48	18.53	19	7.34
11	238	441	57	12.93	318	72.11	23	5.22	20	4.54	23	5.22
Eld Inlet	239	576	131	22.74	328	56.94	10	1.74	81	14.06	26	4.51
	240	40	37	92.50	2	5.00	1	2.50	0	0.00	0	0.00
12	236	273	230	84.25	10	3.66	29	10.62	1	0.37	3	1.10
Budd Inlet	237	886	204	23.02	220	24.83	8	0.90	445	50.23	9	1.02
	241	836	263	31.46	207	24.76	24	2.87	302	36.12	40	4.78
13	242	0	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Port of Olympia	243	0	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
	244	123	112	91.06	1	0.81	7	5.69	1	0.81	2	1.63
14	245	838	418	49.88	100	11.93	232	27.68	8	0.95	80	9.55
Pickering	246	691	509	73.66	20	2.89	137	19.83	2	0.29	23	3.33
Passage/Squaxin	247	1073	522	48.65	52	4.85	130	12.12	15	1.40	354	32.99
15	248	391	82	20.97	185	47.31	37	9.46	72	18.41	15	3.84
Henderson Inlet	249	519	110	21.19	313	60.31	21	4.05	51	9.83	24	4.62
	250	527	55	10.44	398	75.52	10	1.90	50	9.49	14	2.66
16	251	319	260	81.50	15	4.70	38	11.91	1	0.31	5	1.57
Case Inlet	252	188	99	52.66	31	16.49	30	15.96	0	0.00	28	14.89
	253	209	153	73.21	9	4.31	31	14.83	1	0.48	15	7.18

Table 21. Continued.

Stratum	Sample	Total Abundance	Annelida	Annelida % of total abundance	Arthropoda	Arthropoda % of total abundance	Mollusca	Mollusca % of total abundance	Echino-dermata	Echinodermata % of total abundance	Misc. Taxa	Misc. Taxa % of total abundance
17	254	164	48	29.27	73	44.51	36	21.95	1	0.61	6	3.66
Nisqually Reach	255	220	176	80.00	4	1.82	27	12.27	3	1.36	10	4.55
	256	468	290	61.97	34	7.26	30	6.41	98	20.94	16	3.42
18	257	496	403	81.25	25	5.04	21	4.23	2	0.40	45	9.07
Drayton Passage	258	297	93	31.31	86	28.96	86	28.96	27	9.09	5	1.68
	259	687	241	35.08	23	3.35	24	3.49	380	55.31	19	2.77
19	260	244	149	61.07	46	18.85	34	13.93	10	4.10	5	2.05
East Anderson	261	316	213	67.41	19	6.01	42	13.29	25	7.91	17	5.38
Island/No.	262	592	275	46.45	145	24.49	23	3.89	133	22.47	16	2.70
20	263	391	277	70.84	22	5.63	76	19.44	13	3.32	3	0.77
Carr Inlet	264	107	35	32.71	1	0.93	59	55.14	0	0.00	12	11.21
	265	182	113	62.09	8	4.40	59	32.42	0	0.00	2	1.10
21	266	274	150	54.74	18	6.57	96	35.04	0	0.00	10	3.65
Hale Passage	267	266	146	54.89	84	31.58	27	10.15	3	1.13	6	2.26
	268	222	147	66.22	30	13.51	33	14.86	3	1.35	9	4.05
22	269	1107	922	83.29	98	8.85	87	7.86	0	0.00	0	0.00
Gig Harbor	270	1287	1178	91.53	60	4.66	38	2.95	0	0.00	11	0.85
	271	374	98	26.20	142	37.97	108	28.88	23	6.15	3	0.80
23	272	367	205	55.86	102	27.79	48	13.08	2	0.54	10	2.72
Colvos Passage	273	265	133	50.19	86	32.45	31	11.70	5	1.89	10	3.77
	274	633	537	84.83	57	9.00	35	5.53	0	0.00	4	0.63
24	275	510	275	53.92	120	23.53	109	21.37	2	0.39	4	0.78
Quartermaster	276	286	177	61.89	3	1.05	101	35.31	0	0.00	5	1.75
Harbor	277	265	151	56.98	62	23.40	13	4.91	28	10.57	11	4.15

Table 21. Continued.

Stratum	Sample	Total Abundance	Annelida	Annelida % of total abundance	Arthropoda	Arthropoda % of total abundance	Mollusca	Mollusca % of total abundance	Echino-dermata	Echinodermata % of total abundance	Misc. Taxa	Misc. Taxa % of total abundance
25	278	1450	252	17.38	644	44.41	534	36.83	11	0.76	9	0.62
East Passage	279	454	62	13.66	55	12.11	319	70.26	3	0.66	15	3.30
	280	193	124	64.25	29	15.03	34	17.62	1	0.52	5	2.59
26	281	344	144	41.86	33	9.59	158	45.93	3	0.87	6	1.74
Outer	282	533	269	50.47	55	10.32	192	36.02	3	0.56	14	2.63
Commencement Bay	283	723	178	24.62	133	18.40	382	52.84	2	0.28	28	3.87
	284	609	217	35.63	126	20.69	257	42.20	2	0.33	7	1.15
27	285	635	264	41.57	207	32.60	144	22.68	16	2.52	4	0.63
S. E. Commencement	286	758	182	24.01	102	13.46	468	61.74	1	0.13	5	0.66
Bay (shoreline)	287	1879	325	17.30	621	33.05	898	47.79	31	1.65	4	0.21
28	288	1480	1332	90.00	67	4.53	72	4.86	0	0.00	9	0.61
S. E.	289	986	767	77.79	44	4.46	169	17.14	0	0.00	6	0.61
Commencement Bay	290	2291	2124	92.71	52	2.27	109	4.76	0	0.00	6	0.26
29	291	622	215	34.57	22	3.54	378	60.77	5	0.80	2	0.32
N.E. Commencement	292	974	533	54.72	48	4.93	357	36.65	22	2.26	14	1.44
Bay	293	2235	1792	80.18	47	2.10	363	16.24	10	0.45	23	1.03
30	294	304	103	33.88	36	11.84	164	53.95	0	0.00	1	0.33
Thea Foss Waterway	295	2924	2259	77.26	96	3.28	521	17.82	41	1.40	7	0.24
	296	1633	1070	65.52	91	5.57	427	26.15	38	2.33	7	0.43
31	297	1847	1283	69.46	77	4.17	422	22.85	56	3.03	9	0.49
Middle Waterway	298	888	641	72.18	94	10.59	141	15.88	11	1.24	1	0.11
	299	1296	1179	90.97	38	2.93	64	4.94	5	0.39	10	0.77

Table 21. Concluded.

Stratum	Sample	Total Abundance	Annelida	Annelida % of total abundance	Arthropoda	Arthropoda % of total abundance	Mollusca	Mollusca % of total abundance	Echino-dermata	Echinodermata % of total abundance	Misc. Taxa	Misc. Taxa % of total abundance
32	300	889	507	57.03	6	0.67	375	42.18	0	0.00	1	0.11
Blair Waterway	301	1010	726	71.88	6	0.59	278	27.52	0	0.00	0	0.00
	302	1145	672	58.69	28	2.45	440	38.43	4	0.35	1	0.09
33	303	777	572	73.62	22	2.83	177	22.78	0	0.00	6	0.77
Hylebos Waterway	304	535	469	87.66	12	2.24	51	9.53	0	0.00	3	0.56
	305	922	836	90.67	25	2.71	57	6.18	2	0.22	2	0.22

Table 22. Total abundance, taxa richness, Pielou's evenness, and Swartz's Dominance Index for the 1999 southern Puget Sound Sampling stations.

Stratum	Sample	Total Abundance	Taxa Richness	Pielou's Evenness (J')	Swartz's Dominance index
1	206	688	32	0.45	2
Port Ludlow	207	953	58	0.60	6
	208	1574	47	0.64	6
2	209	408	68	0.65	14
Hood Canal (north)	210	517	84	0.78	19
	211	587	92	0.79	22
3	212	1966	82	0.39	2
Port Gamble Bay	213	3476	85	0.33	2
	214	939	59	0.51	6
4	215	753	46	0.80	13
Quilcene Bay	216	744	70	0.79	16
	217	892	81	0.75	15
5	218	281	43	0.74	11
Dabob Bay	219	47	20	0.90	10
	220	26	16	0.95	10
6	221	100	23	0.88	10
Hood Canal (central)	222	219	34	0.74	8
	223	69	29	0.92	14
7	224	139	29	0.71	7
Hood Canal (south)	225	144	15	0.54	2
	226	286	27	0.66	5
8	227	299	33	0.75	8
Port of Shelton	228	237	35	0.79	9
	229	269	45	0.75	10
9	230	297	27	0.44	3
Oakland Bay	231	89	23	0.82	9
	232	82	21	0.88	9
10	233	212	24	0.81	7
Totten Inlet	234	116	18	0.71	4
	235	259	38	0.84	12

Table 22. Continued.

Stratum	Sample	Total Abundance	Taxa Richness	Pielou's Evenness (J')	Swartz's Dominance index
11	238	441	22	0.44	2
Eld Inlet	239	576	29	0.59	4
	240	40	10	0.88	5
12	236	273	23	0.38	2
Budd Inlet	237	886	30	0.48	3
	241	836	39	0.57	4
13	242				
Port of Olympia	243				
	244	123	18	0.64	4
14	245	838	103	0.83	23
Pickering	246	691	98	0.82	25
Passage/Squaxin Island	247	1073	93	0.67	17
15	248	391	27	0.70	6
Henderson Inlet	249	519	29	0.54	4
	250	527	30	0.43	2
16	251	319	47	0.74	11
Case Inlet	252	188	28	0.77	7
	253	209	45	0.82	14
17	254	164	56	0.79	18
Nisqually Reach	255	220	51	0.79	13
	256	468	69	0.78	15
18	257	496	57	0.60	7
Drayton Passage	258	297	81	0.84	24
	259	687	79	0.59	8
19	260	244	53	0.87	18
East Anderson	261	316	63	0.84	20
Island/No. Cormorant Passage	262	592	106	0.78	23
20	263	391	70	0.84	19
Carr Inlet	264	107	22	0.76	7
	265	182	27	0.77	7

Table 22. Continued.

Stratum	Sample	Total Abundance	Taxa Richness	Pielou's Evenness (J')	Swartz's Dominance index
21	266	274	66	0.87	22
Hale Passage	267	266	73	0.78	20
	268	222	57	0.85	17
22	269	1107	61	0.52	3
Gig Harbor	270	1287	78	0.48	3
	271	374	63	0.74	11
23	272	367	96	0.88	31
Colvos Passage	273	265	75	0.84	25
	274	633	54	0.53	4
24	275	510	90	0.80	20
Quartermaster Harbor	276	286	41	0.68	7
	277	265	49	0.84	15
25	278	1450	90	0.63	10
East Passage	279	454	39	0.48	4
	280	193	66	0.86	26
26	281	344	56	0.73	13
Outer	282	533	66	0.64	10
Commencement Bay	283	723	61	0.57	6
	284	609	89	0.73	19
27	285	635	98	0.80	24
S. E. Commencement	286	758	70	0.62	9
Bay (shoreline)	287	1879	101	0.63	9
28	288	1480	65	0.49	6
S. E.	289	986	71	0.72	10
Commencement Bay	290	2291	72	0.49	5
29	291	622	53	0.56	5
N.E. Commencement	292	974	86	0.67	13
Bay	293	2235	86	0.46	4
30	294	304	43	0.77	10
Thea Foss Waterway	295	2924	53	0.43	3
	296	1633	79	0.60	8

Table 22. Concluded.

Stratum	Sample	Total Abundance	Taxa Richness	Pielou's Evenness (J')	Swartz's Dominance index
31	297	1847	117	0.59	12
Middle Waterway	298	888	86	0.70	12
	299	1296	81	0.53	8
32	300	889	50	0.60	5
Blair Waterway	301	1010	50	0.53	3
	302	1145	61	0.58	5
33	303	777	55	0.54	5
Hylebos Waterway	304	535	56	0.59	6
	305	922	47	0.39	2

Table 23. Spearman-rank correlation coefficients (rho, corrected for ties) and significance levels (p) between benthic infaunal indices and measures of grain size (% fines) and % TOC for all 1999 southern Puget Sound sites (n=100).

Benthic index	% Fines (p)	% TOC (p)
Total Abundance	-0.052 ns	-0.234 *
Taxa Richness	-0.301 **	-0.676 ****
Pielou's Evenness (J')	-0.144 ns	-0.155 ns
Swartz's Dominance Index	-0.224 *	-0.480 ****
Annelid Abundance	-0.068 ns	-0.359 ***
Arthropod Abundance	-0.079 ns	-0.262 **
Mollusca Abundance	-0.190 ns	-0.256 *
Echinoderm Abundance	0.058 ns	-0.084 ns
Miscellaneous Taxa Abundance	-0.092 ns	-0.271 **

ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
**** = $p \leq 0.0001$

Table 24. Spearman-rank correlations coefficients (rho, corrected for ties) and significance levels (p) for nine indices of benthic infaunal structure and results of four toxicity tests for all 1999 southern Puget Sound sites (n=100).

Benthic index	Amphipod (p) survival	Urchin (p) fertilization	Microbial (p) biolumin-escence	Cytochrome (p) P450 HRGS
Total Abundance	-0.018 ns	0.176 ns	-0.196 ns	0.306 **
Taxa Richness	-0.047 ns	0.042 ns	0.241 *	-0.121 ns
Pielou's Evenness (J')	0.032 ns	-0.173 ns	0.482 ****	-0.479 ****
Swartz's Dominance Index	0.029 ns	-0.109 ns	0.545 ****	-0.503 ****
Annelid Abundance	-0.061 ns	0.093 ns	-0.124 ns	0.196 ns
Arthropod Abundance	0.008 ns	0.226 *	0.091 ns	-0.105 ns
Mollusca Abundance	0.048 ns	-0.015 ns	0.064 ns	0.219 *
Echinoderm Abundance	-0.092 ns	0.152 ns	-0.041 ns	-0.097 ns
Miscellaneous Taxa Abundance	0.002 ns	0.325 **	0.203 *	-0.330 ***

ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
**** = $p \leq 0.0001$

Table 25. Spearman-rank correlation coefficients (rho, corrected for ties) and significance levels (p) for nine indices of benthic infaunal structure and concentrations of trace metals, chlorinated organic hydrocarbons, and total PAHs, normalized to their respective ERM, SQS, CSL values for all 1999 southern Puget Sound sites (N=100).

Chemical	Total Abundance (p)	Taxa Richness (p)	Pielou's Evenness (J') (p)	Swartz's Dominance (p)	Annelida Abundance (p)	Arthropoda Abundance (p)	Mollusca Abundance (p)	Echinodermata Abundance (p)	Misc. Taxa Abundance (p)
ERM values									
mean ERM quotients for 9 trace metals	-0.236 ns	-0.527 ****	-0.047 ns	-0.295 *	-0.279 ns	-0.271 ns	-0.188 ns	-0.036 ns	-0.199 ns
mean ERM quotients for 13 polynuclear aromatic hydrocarbons	0.401 ***	0.05 ns	-0.419 ***	-0.338 **	0.283 ns	0.027 ns	0.387 ***	-0.09 ns	-0.331 **
mean ERM quotients for 25 substances	0.206 ns	-0.185 ns	-0.354 **	-0.391 ***	0.111 ns	-0.155 ns	0.251 ns	-0.118 ns	-0.326 *
SQS values									
mean SQS quotients for 8 trace metals	-0.138 ns	-0.507 ****	-0.222 ns	-0.428 ***	-0.233 ns	-0.24 ns	-0.164 ns	0.035 ns	-0.16 ns
mean SQS quotients for 6 low molecular weight polynuclear aromatic hydrocarbons	0.505 ****	0.41 ***	-0.369 **	-0.108 ns	0.437 ****	0.203 ns	0.501 ****	-0.059 ns	-0.244 ns
mean SQS quotients for 9 high molecular weight polynuclear aromatic hydrocarbons	0.462 ****	0.415 ***	-0.322 *	-0.086 ns	0.423 ***	0.091 ns	0.439 ****	-0.075 ns	-0.269 ns
mean SQS quotients for 15 polynuclear aromatic hydrocarbons	0.509 ****	0.421 ***	-0.367 **	-0.116 ns	0.455 ****	0.152 ns	0.485 ****	-0.074 ns	-0.274 ns

Table 25. Concluded.

Chemical	Total Abundance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropoda Abundance	(p)	Mollusca Abundance	(p)	Echinodermata Abundance	(p)	Misc. Taxa Abundance	(p)
CSL values																		
mean CSL quotients for 8 trace metals	-0.14	ns	-0.511	****	-0.218	ns	-0.43	***	-0.23	ns	-0.252	ns	-0.162	ns	0.016	ns	-0.175	ns
mean CSL quotients for 6 low molecular weight polynuclear aromatic hydrocarbons	0.5	****	0.402	***	-0.368	**	-0.109	ns	0.43	****	0.212	ns	0.5	****	-0.055	ns	-0.244	ns
mean CSL quotients for 9 high molecular weight polynuclear aromatic hydrocarbons	0.458	****	0.419	***	-0.319	*	-0.083	ns	0.42	***	0.086	ns	0.438	****	-0.072	ns	-0.265	ns
mean CSL quotients for 15 polynuclear aromatic hydrocarbons	0.509	****	0.416	***	-0.375	**	-0.124	ns	0.453	****	0.157	ns	0.485	****	-0.075	ns	-0.274	ns

ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
**** = $p \leq 0.0001$

Table 26. Spearman-rank correlation coefficients (rho, corrected for ties) and significance levels (p) for nine indices of benthic infaunal structure and concentrations of partial digestion metals in sediments for all 1999 southern Puget Sound sites (n=100).

Chemical	Total Abundance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropoda Abundance	(p)	Mollusca Abundance	(p)	Echinodermata Abundance	(p)	Misc. Taxa Abundance	(p)
Aluminum	-0.417	**	-0.750	****	-0.009	ns	-0.379	*	-0.446	***	-0.434	**	-0.343	ns	-0.184	ns	-0.157	ns
Antimony	0.420	ns	-0.018	ns	-0.398	ns	-0.334	ns	0.358	ns	-0.055	ns	0.477	ns	-0.191	ns	-0.330	ns
Arsenic	0.079	ns	-0.274	ns	-0.329	ns	-0.375	*	0.022	ns	-0.157	ns	0.054	ns	0.098	ns	-0.042	ns
Barium	0.086	ns	-0.268	ns	-0.269	ns	-0.316	ns	-0.062	ns	-0.150	ns	0.128	ns	0.014	ns	0.001	ns
Beryllium	-0.416	**	-0.688	****	0.070	ns	-0.262	ns	-0.438	***	-0.353	ns	-0.335	ns	-0.109	ns	-0.110	ns
Cadmium	-0.276	ns	-0.593	****	-0.148	ns	-0.439	*	-0.357	ns	-0.245	ns	-0.477	**	-0.012	ns	-0.223	ns
Calcium	-0.122	ns	-0.405	**	-0.032	ns	-0.196	ns	-0.163	ns	-0.204	ns	-0.043	ns	0.001	ns	-0.011	ns
Chromium	-0.519	****	-0.694	****	0.145	ns	-0.213	ns	-0.542	****	-0.318	ns	-0.395	**	-0.169	ns	-0.161	ns
Cobalt	-0.468	***	-0.582	****	0.188	ns	-0.099	ns	-0.487	****	-0.299	ns	-0.318	ns	-0.150	ns	-0.032	ns
Copper	-0.079	ns	-0.424	**	-0.171	ns	-0.358	ns	-0.120	ns	-0.330	ns	-0.036	ns	-0.083	ns	-0.205	ns
Iron	-0.385	*	-0.705	****	-0.002	ns	-0.338	ns	-0.437	***	-0.406	**	-0.245	ns	-0.226	ns	-0.210	ns
Lead	-0.009	ns	-0.285	ns	-0.251	ns	-0.344	ns	-0.112	ns	-0.145	ns	-0.090	ns	0.075	ns	-0.092	ns
Magnesium	-0.472	***	-0.712	****	0.082	ns	-0.262	ns	-0.520	****	-0.356	*	-0.350	ns	-0.166	ns	-0.101	ns
Manganese	-0.537	****	-0.341	ns	0.439	**	0.232	ns	-0.445	***	-0.179	ns	-0.408	**	-0.044	ns	0.206	ns
Mercury	-0.026	ns	-0.381	*	-0.263	ns	-0.404	**	-0.170	ns	-0.096	ns	-0.089	ns	0.076	ns	-0.135	ns
Nickel	-0.533	****	-0.589	****	0.256	ns	-0.043	ns	-0.552	****	-0.217	ns	-0.339	ns	-0.152	ns	-0.082	ns
Potassium	-0.369	*	-0.683	****	-0.065	ns	-0.384	*	-0.423	**	-0.395	**	-0.358	*	-0.097	ns	-0.144	ns
Selenium	-0.493	**	-0.710	****	0.112	ns	-0.224	ns	-0.623	****	-0.210	ns	-0.581	****	0.031	ns	-0.169	ns
Silver	0.073	ns	-0.204	ns	-0.331	ns	-0.377	ns	-0.108	ns	-0.041	ns	-0.060	ns	0.160	ns	0.044	ns
Sodium	-0.380	*	-0.758	****	-0.100	ns	-0.454	***	-0.452	***	-0.402	**	-0.402	**	-0.130	ns	-0.157	ns
Thallium	0.142	ns	0.061	ns	-0.070	ns	-0.117	ns	0.117	ns	-0.241	ns	0.022	ns	-0.258	ns	-0.418	ns
Vanadium	-0.223	ns	-0.535	****	-0.022	ns	-0.275	ns	-0.230	ns	-0.317	ns	-0.069	ns	-0.150	ns	-0.131	ns
Zinc	-0.281	ns	-0.643	****	-0.112	ns	-0.409	**	-0.355	ns	-0.368	*	-0.264	ns	-0.077	ns	-0.183	ns

ns = $p > 0.05$
* = $p \le 0.05$
** = $p \le 0.01$
*** = $p \le 0.001$
**** = $p \le 0.0001$

Table 27. Spearman-rank correlation coefficients (rho, corrected for ties) and significance levels (p) for nine indices of benthic infaunal structure and concentrations of total digestion metals in sediments for all 1999 southern Puget Sound sites (n=100).

Chemical	Total Abundance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropoda Abundance	(p)	Mollusca Abundance	(p)	Echinodermata Abundance	(p)	Misc. Taxa Abundance	(p)
Aluminum	0.181	ns	-0.173	ns	-0.352	ns	-0.391	*	0.048	ns	0.006	ns	0.055	ns	0.093	ns	-0.003	ns
Antimony	0.240	ns	0.262	ns	-0.055	ns	0.091	ns	0.280	ns	0.114	ns	0.416	ns	-0.070	ns	-0.180	ns
Arsenic	0.086	ns	-0.285	ns	-0.323	ns	-0.382	*	0.023	ns	-0.152	ns	0.047	ns	0.107	ns	-0.045	ns
Barium	0.150	ns	-0.062	ns	-0.222	ns	-0.227	ns	0.023	ns	0.251	ns	0.057	ns	0.230	ns	0.039	ns
Beryllium	-0.190	ns	-0.126	ns	0.318	ns	0.234	ns	-0.093	ns	-0.149	ns	-0.051	ns	-0.093	ns	-0.091	ns
Cadmium	-0.221	ns	-0.590	****	-0.224	ns	-0.499	****	-0.293	ns	-0.269	ns	-0.389	*	0.030	ns	-0.193	ns
Calcium	0.294	ns	-0.121	ns	-0.342	ns	-0.336	ns	0.211	ns	0.077	ns	0.206	ns	0.122	ns	0.030	ns
Chromium	-0.364	*	-0.549	****	0.127	ns	-0.172	ns	-0.407	**	-0.207	ns	-0.225	ns	-0.223	ns	-0.145	ns
Cobalt	-0.305	ns	-0.416	**	0.150	ns	-0.036	ns	-0.253	ns	-0.241	ns	-0.200	ns	-0.053	ns	0.001	ns
Copper	0.087	ns	-0.307	ns	-0.269	ns	-0.417	*	0.086	ns	-0.334	ns	0.106	ns	-0.128	ns	-0.314	ns
Iron	-0.251	ns	-0.623	****	-0.056	ns	-0.357	ns	-0.289	ns	-0.405	**	-0.194	ns	-0.158	ns	-0.152	ns
Lead	0.068	ns	-0.182	ns	-0.268	ns	-0.302	ns	-0.051	ns	-0.090	ns	-0.036	ns	0.072	ns	-0.046	ns
Magnesium	-0.088	ns	-0.407	**	-0.088	ns	-0.292	ns	-0.198	ns	-0.054	ns	-0.014	ns	-0.022	ns	-0.071	ns
Manganese	-0.371	*	-0.217	ns	0.394	*	0.252	ns	-0.238	ns	-0.132	ns	-0.236	ns	0.028	ns	0.222	ns
Nickel	-0.519	****	-0.564	****	0.272	ns	-0.045	ns	-0.532	****	-0.164	ns	-0.450	***	-0.097	ns	-0.041	ns
Potassium	0.141	ns	0.006	ns	-0.158	ns	-0.123	ns	0.110	ns	-0.035	ns	0.140	ns	0.070	ns	0.034	ns
Selenium	-0.600	****	-0.768	****	0.172	ns	-0.266	ns	-0.574	****	-0.398	ns	-0.633	****	-0.131	ns	-0.223	ns
Sodium	-0.310	ns	-0.677	****	-0.129	ns	-0.464	***	-0.378	*	-0.297	ns	-0.445	***	-0.091	ns	-0.094	ns
Thallium	0.077	ns	0.075	ns	-0.088	ns	-0.063	ns	0.084	ns	-0.083	ns	-0.013	ns	0.087	ns	-0.098	ns
Titanium	0.157	ns	-0.001	ns	-0.190	ns	-0.242	ns	0.094	ns	-0.052	ns	0.005	ns	-0.229	ns	-0.258	ns
Vanadium	-0.241	ns	-0.552	****	-0.020	ns	-0.275	ns	-0.207	ns	-0.353	ns	-0.054	ns	-0.155	ns	-0.130	ns
Zinc	-0.163	ns	-0.560	****	-0.170	ns	-0.418	**	-0.250	ns	-0.350	ns	-0.177	ns	-0.062	ns	-0.141	ns
Silicon	0.199	ns	0.527	****	0.118	ns	0.354	ns	0.243	ns	0.387	*	0.156	ns	0.080	ns	0.147	ns
Tin	0.151	ns	-0.223	ns	-0.343	ns	-0.386	*	0.020	ns	-0.125	ns	0.118	ns	-0.001	ns	-0.149	ns

ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
**** = $p \leq 0.0001$

Table 28. Spearman-rank correlation coefficients (rho, corrected for ties) and significance levels (p) for nine indices of benthic infaunal structure and concentrations of Low Molecular Weight Polynuclear Aromatic Hydrocarbons (LPAH) in sediments for all 1999 southern Puget Sound sites (N=100).

Chemical	Total Abun-dance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Domi-nance	(p)	Annelida Abun-dance	(p)	Arthro-poda Abun-dance	(p)	Mollusca Abundance	(p)	Echino-dermata Abun-dance	(p)	Misc. Taxa Abun-dance	(p)
1,6,7-Trimethylnaphthalene	0.254	ns	-0.053	ns	-0.349	ns	-0.280	ns	0.131	ns	-0.038	ns	0.286	ns	0.011	ns	-0.110	ns
1-Methylnaphthalene	0.299	ns	-0.101	ns	-0.425	**	-0.381	*	0.169	ns	-0.050	ns	0.322	ns	-0.099	ns	-0.247	ns
1-Methylphenanthrene	0.329	ns	0.012	ns	-0.392	*	-0.306	ns	0.194	ns	0.018	ns	0.327	ns	-0.022	ns	-0.148	ns
2,6-Dimethylnaphthalene	0.145	ns	-0.273	ns	-0.397	**	-0.455	***	0.024	ns	-0.177	ns	0.110	ns	-0.062	ns	-0.218	ns
2-Methylnaphthalene	0.305	ns	-0.055	ns	-0.394	*	-0.335	ns	0.168	ns	-0.037	ns	0.342	ns	-0.084	ns	-0.248	ns
2-Methylphenanthrene	0.306	ns	-0.034	ns	-0.407	**	-0.350	ns	0.160	ns	-0.013	ns	0.282	ns	-0.042	ns	-0.210	ns
Acenaphthene	0.455	**	0.143	ns	-0.459	**	-0.331	ns	0.326	ns	0.068	ns	0.385	*	0.013	ns	-0.240	ns
Acenaphthylene	0.356	ns	-0.029	ns	-0.468	***	-0.435	**	0.229	ns	0.090	ns	0.274	ns	-0.064	ns	-0.322	ns
Anthracene	0.421	**	-0.017	ns	-0.503	****	-0.452	***	0.288	ns	0.020	ns	0.329	ns	-0.088	ns	-0.329	ns
Biphenyl	0.398	*	0.227	ns	-0.333	ns	-0.156	ns	0.267	ns	0.111	ns	0.379	ns	0.007	ns	-0.234	ns
Dibenzothiophene	0.364	*	-0.037	ns	-0.442	**	-0.404	**	0.211	ns	-0.016	ns	0.329	ns	-0.058	ns	-0.294	ns
Fluorene	0.363	*	-0.039	ns	-0.446	***	-0.404	**	0.224	ns	-0.013	ns	0.346	ns	-0.138	ns	-0.326	ns
Naphthalene	0.376	*	0.018	ns	-0.422	**	-0.348	ns	0.222	ns	0.083	ns	0.342	ns	-0.036	ns	-0.264	ns
Phenanthrene	0.404	**	-0.030	ns	-0.493	****	-0.454	***	0.254	ns	0.040	ns	0.327	ns	-0.097	ns	-0.329	ns
Retene	0.280	ns	-0.024	ns	-0.380	*	-0.294	ns	0.147	ns	0.053	ns	0.301	ns	0.012	ns	-0.126	ns
Sum of 6 LPAH^	0.502	****	0.379	*	-0.381	*	-0.135	ns	0.434	**	0.205	ns	0.479	****	-0.065	ns	-0.259	ns
Sum of 7 LPAH^^	0.394	*	-0.037	ns	-0.491	****	-0.452	***	0.251	ns	0.040	ns	0.327	ns	-0.095	ns	-0.334	ns
Total LPAH	0.357	ns	-0.040	ns	-0.468	***	-0.410	**	0.227	ns	0.020	ns	0.338	ns	-0.081	ns	-0.271	ns

^6 LPAH = defined by WA Ch. 173-204 RCW; Acenaphthene, Acenaphthylene, Anthracene, Fluorene, Naphthalene, Phenanthrene, carbon normalized.
^^7LPAH = defined by Long et. Al., 1995; Acenaphthene, Acenaphthylene, Anthracene, Fluorene, 2-Methylnaphthalene, Naphthalene, Phenanthrene
ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
**** = $p \leq 0.0001$

Table 29. Spearman-rank correlation coefficients (rho, corrected for ties) and significance levels (p) for nine indices of benthic infaunal structure and concentrations of High Molecular Weight Polynuclear Aromatic Hydrocarbons (HPAH) in sediments for all 1999 southern Puget Sound sites (N=100).

Chemical	Total Abundance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Dominance	(p)	Annelida Abundance	(p)	Arthropoda Abundance	(p)	Mollusca Abundance	(p)	Echinodermata Abundance	(p)	Misc. Taxa Abundance	(p)
Benzo(a)anthracene	0.374	*	-0.070	ns	-0.484	****	-0.472	***	0.233	ns	-0.040	ns	0.301	ns	-0.111	ns	-0.349	ns
Benzo(a)pyrene	0.372	*	-0.063	ns	-0.488	****	-0.480	***	0.226	ns	-0.021	ns	0.300	ns	-0.117	ns	-0.343	ns
Benzo(b)fluoranthene	0.232	ns	-0.229	ns	-0.458	***	-0.521	****	0.060	ns	-0.092	ns	0.138	ns	-0.110	ns	-0.332	ns
Benzo(e)pyrene	0.305	ns	-0.149	ns	-0.471	***	-0.502	****	0.175	ns	-0.103	ns	0.253	ns	-0.115	ns	-0.365	*
Benzo(g,h,i)perylene	0.268	ns	-0.115	ns	-0.414	**	-0.449	***	0.140	ns	-0.125	ns	0.265	ns	-0.141	ns	-0.375	*
Benzo(k)fluoranthene	0.331	ns	-0.001	ns	-0.373	*	-0.359	ns	0.275	ns	-0.099	ns	0.396	*	-0.161	ns	-0.362	ns
Chrysene	0.342	ns	-0.099	ns	-0.462	***	-0.467	***	0.204	ns	-0.043	ns	0.281	ns	-0.098	ns	-0.351	ns
Dibenzo(a,h)anthracene	0.362	ns	0.192	ns	-0.329	ns	-0.149	ns	0.198	ns	-0.039	ns	0.369	ns	0.030	ns	-0.219	ns
Fluoranthene	0.406	**	-0.071	ns	-0.526	****	-0.520	****	0.264	ns	0.005	ns	0.291	ns	-0.111	ns	-0.373	*
Indeno(1,2,3-c,d)pyrene	0.292	ns	-0.046	ns	-0.404	**	-0.391	*	0.192	ns	-0.116	ns	0.278	ns	-0.133	ns	-0.391	*
Perylene	0.172	ns	-0.256	ns	-0.358	ns	-0.442	***	0.042	ns	-0.243	ns	0.200	ns	-0.155	ns	-0.382	*
Pyrene	0.415	**	-0.045	ns	-0.532	****	-0.506	****	0.274	ns	0.041	ns	0.272	ns	-0.075	ns	-0.372	*
sum of 6 HPAH^	0.395	*	-0.072	ns	-0.517	****	-0.508	****	0.252	ns	-0.005	ns	0.295	ns	-0.105	ns	-0.372	*
sum of 9 HPAH^^	0.489	****	0.378	*	-0.373	*	-0.148	ns	0.434	**	0.136	ns	0.434	**	-0.066	ns	-0.272	ns
Total HPAH	0.354	ns	-0.109	ns	-0.493	****	-0.505	****	0.211	ns	-0.055	ns	0.283	ns	-0.122	ns	-0.379	*
sum of 13 PAH^^^	0.418	**	-0.046	ns	-0.524	****	-0.495	****	0.269	ns	0.029	ns	0.312	ns	-0.102	ns	-0.354	ns
Sum of 15 PAH^^^^	0.508	****	0.383	*	-0.384	*	-0.155	ns	0.445	***	0.160	ns	0.455	***	-0.069	ns	-0.285	ns
Total all PAH	0.386	*	-0.058	ns	-0.505	****	-0.473	***	0.241	ns	-0.015	ns	0.324	ns	-0.105	ns	-0.340	ns

^6HPAH = defined by Long et. Al., 1995; Benzo(a)anthracene, Benzo(a)pyrene, Chrysene, Dibenzo(a,h)anthracene, Fluoranthene, Pyrene
^^9HPAH = defined by WA Ch. 173-204 RCW; Benzo(a)anthracene, Benzo(a)pyrene, Indeno(1,2,3,-c,d)pyrene, Benzo(g,h,i)perylene, Chrysene, Dibenzo(a,h)anthracene, Fluoranthene, Pyrene, Total Benzofluranthenes, carbon normalized
^^^13PAH = 7LPAH and 6HPAH
^^^^15PAH= 6LPAH and 9HPAH
ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
**** = $p \leq 0.0001$

Table 30. Spearman-rank correlation coefficients (rho, corrected for ties) and significance levels (p) for nine indices of benthic infaunal structure and concentrations of DDT and PCB compounds in sediments for all 1999 southern Puget Sound sites (N=100).

Chemical	Total Abun- dance (p)	Taxa Richness (p)	Pielou's Evenness (J') (p)	Swartz's Domi- nance (p)	Annelida Abundance (p)	Arthropoda Abundance (p)	Mollusca Abundance (p)	Echino- dermata Abun- dance (p)	Misc. Taxa Abun- dance (p)
4,4'-DDD	-0.018 ns	0.085 ns	-0.200 ns	-0.012 ns	0.036 ns	0.159 ns	-0.355 ns	0.133 ns	0.394 ns
4,4'-DDE	0.033 ns	-0.067 ns	-0.017 ns	-0.261 ns	-0.030 ns	0.091 ns	0.176 ns	-0.627 ns	-0.018 ns
4,4'-DDT	-0.116 ns	0.029 ns	-0.493 ns	-0.088 ns	0.203 ns	-0.074 ns	-0.058 ns	-0.426 ns	0.588 ns
Total DDT	-0.056 ns	-0.037 ns	0.025 ns	0.002 ns	-0.143 ns	0.111 ns	-0.098 ns	-0.164 ns	0.295 ns
PCB Aroclor 1248	-0.071 ns	-0.238 ns	0.071 ns	-0.246 ns	-0.310 ns	0.071 ns	0.429 ns	-0.446 ns	-0.108 ns
PCB Aroclor 1254	0.312 ns	0.292 ns	-0.016 ns	0.119 ns	0.209 ns	-0.108 ns	0.147 ns	-0.024 ns	-0.232 ns
PCB Aroclor 1260	0.082 ns	-0.063 ns	-0.128 ns	-0.066 ns	0.220 ns	-0.128 ns	-0.010 ns	-0.038 ns	-0.315 ns
PCB Aroclor 1268	-0.800 ns	-0.400 ns	0.600 ns	0.000 ns	-0.800 ns	-0.800 ns	0.800 ns	-0.949 ns	-0.400 ns
Total PCB Aroclor	0.470 ns	0.485 ns	-0.064 ns	0.132 ns	0.416 ns	0.079 ns	0.294 ns	0.092 ns	0.039 ns
PCB Congener 28	0.000 ns	-0.214 ns	0.679 ns	0.162 ns	-0.024 ns	0.262 ns	0.357 ns	-0.342 ns	-0.205 ns
PCB Congener 44	-0.476 ns	-0.838 ns	-0.095 ns	-0.551 ns	-0.500 ns	-0.617 ns	-0.050 ns	-0.627 ns	-0.370 ns
PCB Congener 52	-0.157 ns	-0.529 ns	-0.154 ns	-0.241 ns	0.060 ns	-0.497 ns	-0.193 ns	-0.373 ns	-0.270 ns
PCB Congener 66	-0.611 ns	-0.850 ns	0.048 ns	-0.337 ns	-0.326 ns	-0.351 ns	0.176 ns	-0.529 ns	-0.084 ns
PCB Congener 101	0.268 ns	0.393 ns	0.273 ns	0.441 ns	0.099 ns	0.030 ns	0.093 ns	0.145 ns	0.013 ns
PCB Congener 105	-0.643 ns	-0.857 ns	0.286 ns	-0.252 ns	-0.147 ns	-0.029 ns	0.416 ns	-0.303 ns	-0.042 ns
PCB Congener 118	0.364 ns	0.249 ns	-0.028 ns	0.069 ns	0.176 ns	-0.242 ns	0.216 ns	-0.001 ns	-0.322 ns
PCB Congener 128	-0.310 ns	-0.690 ns	0.286 ns	-0.120 ns	0.067 ns	0.213 ns	0.650 ns	-0.058 ns	0.226 ns
PCB Congener 138	0.261 ns	0.250 ns	-0.007 ns	0.085 ns	0.208 ns	-0.064 ns	0.017 ns	0.086 ns	-0.076 ns
PCB Congener 153	0.263 ns	0.243 ns	-0.109 ns	0.016 ns	0.170 ns	0.029 ns	0.023 ns	0.053 ns	-0.027 ns
PCB Congener 170	-0.382 ns	-0.900 ns	0.103 ns	-0.225 ns	0.063 ns	0.028 ns	0.350 ns	-0.123 ns	0.067 ns
PCB Congener 180	0.244 ns	0.007 ns	-0.053 ns	-0.044 ns	0.216 ns	-0.116 ns	0.227 ns	0.083 ns	-0.148 ns
PCB Congener 187	0.054 ns	-0.147 ns	0.263 ns	0.127 ns	0.253 ns	-0.059 ns	0.226 ns	0.020 ns	-0.216 ns
PCB Congener 206	-0.396 ns	-0.511 ns	-0.159 ns	-0.336 ns	0.341 ns	-0.176 ns	0.141 ns	-0.357 ns	0.159 ns
Total PCB Congeners	0.420 ns	0.350 ns	-0.316 ns	-0.117 ns	0.308 ns	0.079 ns	0.155 ns	-0.007 ns	-0.123 ns

ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
**** = $p \leq 0.0001$

Table 31. Spearman-rank correlation coefficients (rho, corrected for ties) and significance levels (p) for nine indices of benthic infaunal structure and concentrations of organotin and organic compounds in sediments for all 1999 southern Puget Sound sites (N=100).

Chemical	Total Abun-dance	(p)	Taxa Richness	(p)	Pielou's Evenness (J')	(p)	Swartz's Domi-nance	(p)	An-nelida Abun-dance	(p)	Arthrop-oda Abun-dance	(p)	Mollusca Abun-dance	(p)	Echino-dermata Abun-dance	(p)	Misc. Taxa Abun-dance	(p)
Organotins																		
Dibutyltin Dichloride	0.200	ns	0.093	ns	-0.268	ns	0.199	ns	0.377	ns	0.152	ns	0.007	ns	0.123	ns	0.422	ns
Monobutyltin Trichloride	-0.057	ns	-0.134	ns	0.066	ns	0.295	ns	0.263	ns	-0.092	ns	0.115	ns	0.077	ns	0.102	ns
Tributyltin Chloride	0.245	ns	-0.026	ns	-0.097	ns	0.084	ns	0.267	ns	0.023	ns	0.275	ns	0.154	ns	-0.100	ns
Phenols																		
2-Methylphenol	0.039	ns	-0.344	ns	-0.175	ns	-0.418	ns	-0.147	ns	0.398	ns	-0.091	ns	0.537	ns	0.163	ns
4-Methylphenol	0.123	ns	-0.211	ns	-0.285	ns	-0.370	ns	-0.037	ns	-0.165	ns	-0.119	ns	-0.217	ns	-0.379	ns
Pentachlorophenol	-0.655	ns	-0.618	ns	0.427	ns	0.458	ns	-0.591	ns	0.182	ns	-0.627	ns	-0.067	ns	-0.243	ns
Phenol	-0.545	ns	-0.776	ns	-0.490	ns	-0.774	ns	-0.552	ns	-0.252	ns	-0.706	ns	-0.303	ns	-0.495	ns
Miscellaneous																		
1,4-Dichlorobenzene	0.104	ns	0.022	ns	0.109	ns	0.056	ns	-0.030	ns	-0.055	ns	0.346	ns	-0.019	ns	0.097	ns
9(H)Carbazole	0.339	ns	-0.070	ns	-0.431	**	-0.409	**	0.181	ns	-0.002	ns	0.265	ns	-0.082	ns	-0.329	ns
Benzoic Acid	-0.440	ns	-0.219	ns	0.259	ns	0.140	ns	-0.422	ns	-0.248	ns	-0.534	*	0.340	ns	0.076	ns
Benzyl Alcohol	0.561	ns	-0.083	ns	-0.467	ns	-0.583	ns	0.133	ns	0.267	ns	-0.283	ns	0.017	ns	0.483	ns
Bis(2-Ethylhexyl) Phthalate	-0.143	ns	0.029	ns	0.257	ns	0.145	ns	-0.214	ns	-0.536	ns	0.036	ns	-0.778	ns	-0.847	ns
Butylbenzylphthalate	0.900	ns	0.200	ns	-0.900	ns	-0.700	ns	0.700	ns	0.700	ns	0.600	ns	0.600	ns	0.051	ns
Dibenzofuran	0.359	ns	-0.070	ns	-0.457	***	-0.427	**	0.214	ns	-0.032	ns	0.313	ns	-0.095	ns	-0.318	ns
Diethylphthalate	0.600	ns	-0.029	ns	-0.943	ns	-0.771	ns	0.771	ns	-0.086	ns	0.371	ns	-0.174	ns	0.116	ns
Dimethylphthalate	0.500	ns	0.095	ns	0.143	ns	0.293	ns	-0.017	ns	0.084	ns	0.753	ns	0.607	ns	0.316	ns
Hexachlorobenzene	0.244	ns	0.092	ns	-0.235	ns	-0.215	ns	0.156	ns	-0.361	ns	-0.108	ns	-0.525	ns	-0.148	ns
Hexachlorobutadiene	0.975	ns	0.667	ns	0.359	ns	0.359	ns	0.359	ns	0.359	ns	0.205	ns	0.368	ns	-0.359	ns

ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
**** = $p \leq 0.0001$

Table 32. Percentages of southern Puget Sound study area with indices of degraded sediments based upon the sediment quality triad of data.

Sediment Quality Index Category (number of parameters impaired /station)	No. (%) of stations		km^2	(%) of total study area
1999 Southern Puget Sound	**100**	**(100.0)**	**857.7**	**(100.0)**
High (no parameter impaired)	36	(36.0)	493.5	(57.5)
Intermediate/High (one parameter impaired chemistry, toxicity, or benthos)	35	(35.0)	274.1	(32.0)
Intermediate/Degraded (two parameters impaired chemistry, toxicity, or benthos)	18	(18.0)	85.7	(10.0)
Degraded (three parameters impaired chemistry, toxicity, or benthos)	11	(11.0)	4.4	(0.5)

Table 33. Estimated spatial extent of toxicity in three regions of Puget Sound and in the entire survey area at levels exceeding critical values. (Shaded area = total number of stations and area of each region)

Toxicity Test Criteria	No. (%) of stations		km^2	(%) of total study area
1997 Northern Puget Sound	**100**	**(100.0)**	**773.9**	**(100.0)**
Amphipod survival				
<80% of controls	0	(0.0)	0.0	(0.0)
Urchin fertilization (<80% of controls)				
100% pore water	15	(15.0)	40.6	(5.2)
50% pore water	7	(7.0)	11.5	(1.5)
25% pore water	6	(6.0)	8.3	(1.1)
Microbial bioluminescence				
<80% of controls	98	(98.0)	761.9	(98.4)
<0.51 mg/mL	5	(5.0)	9.0	(1.2)
<0.06 mg/mL	0	(0.0)	0.0	(0.0)
Cytochrome P450 HRGS				
>11.1 μg/g	15	(15.0)	20.1	(2.6)
>37.1 μg/g	4	(4.0)	0.2	(0.03)
1998 Central Puget Sound	**100**	**(100.0)**	**731.7**	**(100.0)**
Amphipod survival				
<80% of controls	1	(1.0)	1.0	(0.1)
Urchin fertilization (<80% of controls)				
100% pore water	9	(9.0)	4.0	(0.5)
50% pore water	3	(3.0)	1.5	(0.2)
25% pore water	3	(3.0)	4.2	(0.6)
Microbial bioluminescence				
<80% of controls	61	(61.0)	348.9	(47.7)
<0.51 mg/mL	0	(0.0)	0.0	(0.0)
<0.06 mg/mL	0	(0.0)	0.0	(0.0)
Cytochrome P450 HRGS				
>11.1 μg/g	62	(62.0)	237.1	(32.4)
>37.1 μg/g	27	(27.0)	23.7	(3.2)
1999 Southern Puget Sound	**100**	**(100.0)**	**857.7**	**(100.0)**
Amphipod survival				
<80% of controls	0	(0.0)	0.0	(0.0)
Urchin fertilization (<80% of controls)				
100% pore water	8	(8.0)	48.9	(5.7)
50% pore water	4	(4.0)	4.7	(0.5)
25% pore water	3	(3.0)	2.2	(0.3)

Table 33. Concluded.

Toxicity Test Criteria	No. (%) of stations		km^2	(%) of total study area
Microbial bioluminescence				
<80% of controls	78	(78.0)	518.6	(60.5)
<0.51 mg/mL	3	(3.0)	1.5	(0.2)
<0.06 mg/mL	0	(0.0)	0.0	(0.0)
Cytochrome P450 HRGS				
>11.1 µg/g	57	(57.0)	329.2	(38.4)
>37.1 µg/g	17	(17.0)	43.1	(5.0)
Total Study Area	**300**	**(100.0)**	**2363.3**	**(100.0)**
Amphipod survival				
<80% of controls	1	(0.3)	1.0	(0.04)
Urchin fertilization (<80% of controls)				
100% pore water	32	(10.7)	93.5	(4.0)
50% pore water	14	(4.7)	17.7	(0.7)
25% pore water	12	(4.0)	14.6	(0.6)
Microbial bioluminescence				
<80% of controls	237	(79.0)	1629.3	(68.9)
<0.51 mg/mL	8	(2.7)	10.5	(0.4)
<0.06 mg/mL	0	(0.0)	0.0	(0.0)
Cytochrome P450 HRGS				
>11.1 µg/g	134	(44.7)	586.3	(24.8)
>37.1 µg/g	48	(16.0)	67.0	(2.8)

Table 34. Spatial extent of toxicity (km^2 and percentages of total area) in amphipod survival tests performed with solid-phase sediments from 27 U.S. bays and estuaries. Unless specified otherwise, test animals were *Ampelisca abdita*.

				Amphipod survival**	
Survey Areas	Year sampled	No. of sediment samples	Total area of survey (km^2)	Toxic area (km^{-2})	Pct. of area toxic
Newark Bay	93	57	13	10.8	85.0%
San Diego Bay*	93	117	40.2	26.3	65.8%
California coastal lagoons	94	30	5	2.9	57.9%
Tijuana River*	93	6	0.3	0.2	56.2%
Long Island Sound	91	60	71.9	36.3	50.5%
Hudson-Raritan Estuary	91	117	350	133.3	38.1%
San Pedro Bay*	92	105	53.8	7.8	14.5%
Biscayne Bay	95/96	226	484.2	62.3	12.9%
Boston Harbor	93	55	56.1	5.7	10.0%
Delaware Bay	97	73	2346.8	145.4	6.2%
Savannah River	94	60	13.1	0.2	1.2%
St. Simons Sound	94	20	24.6	0.1	0.4%
Tampa Bay	92/93	165	550	0.5	0.1%
central Puget Sound	98	100	737	1.0	0.1%
Pensacola Bay	93	40	273	0.04	0.0%
Galveston Bay	96	75	1351.1	0	0.0%
southern Puget Sound	99	100	857.7	0	0.0%
northern Puget Sound	97	100	773.9	0	0.0%
Choctawhatchee Bay	94	37	254.5	0	0.0%
Sabine Lake	95	66	245.9	0	0.0%
Apalachicola Bay	94	9	187.6	0	0.0%
St. Andrew Bay	93	31	127.2	0	0.0%
Charleston Harbor	93	63	41.1	0	0.0%
Winyah Bay	93	9	7.3	0	0.0%
Mission Bay*	93	11	6.1	0	0.0%
Leadenwah Creek	93	9	1.7	0	0.0%
San Diego River*	93	2	0.5	0	0.0%
Cumulative National estuarine average based upon data collected through:					
•1997		1543	7278.8	431.8	5.9%

* tests performed with *Rhepoxynius abronius*

** Critical value <80% of mean percent survival in control

Table 35. Spatial extent of toxicity (km^2 and percentages of total area) in sea urchin fertilization tests performed with 100% sediment pore waters from 23 U. S. bays and estuaries. Unless specified differently, tests performed with *Arbacia punctulata*.

Survey areas	Year sampled	No. of sediment samples	Total area of survey (km^2)	Urchin fertilization in 100% pore waters* Toxic area (km^2)	Pct. of area toxic
San Pedro Bay[a]	92	105	53.8	52.6	97.7%
Tampa Bay	92/93	165	550	463.6	84.3%
San Diego Bay[b]	93	117	40.2	25.6	76.0%
Mission Bay[b]	93	11	6.1	4	65.9%
Tijuana River[b]	93	6	0.3	0.2	56.2%
San Diego River[b]	93	2	0.5	0.3	52.0%
Biscayne Bay	95/96	226	484.2	229.5	47.4%
Choctawhatchee Bay	94	37	254.5	113.1	44.4%
California coastal lagoons	94	30	5	2.1	42.7%
Winyah Bay	93	9	7.3	3.1	42.2%
Apalachicola Bay	94	9	187.6	63.6	33.9%
Galveston Bay	96	75	1351.1	432	32.0%
Charleston Harbor	93	63	41.1	12.5	30.4%
Savannah River	94	60	13.1	2.42	18.4%
Delaware Bay	97	73	2346.8	247.5	10.5%
Boston Harbor	93	55	56.1	3.8	6.6%
southern Puget Sound[c]	99	100	857.7	48.9	5.7%
Sabine Lake	95	66	245.9	14	5.7%
Pensacola Bay	93	40	273	14.4	5.3%
northern Puget Sound[c]	97	100	773.9	40.6	5.2%
St. Simons Sound	94	20	24.6	0.7	2.6%
St. Andrew Bay	93	31	127.2	2.3	1.8%
central Puget Sound[c]	98	100	731.7	4.4	0.5%
Leadenwah Creek	93	9	1.7	0	0.0%
Cumulative National estuarine average based upon data collected through:					
•1997		1309	6837.8	1728	25.3%

[a] Tests performed for embryological development of *Haliotis rufescens*

[b] Tests performed for embryological development of *Strongylocentrotus purpuratus*

[c] Tests performed for fertilization success of *S. purpuratus*

* Critical value <80% of control

Table 36. Spatial extent of toxicity (km^2 and percentages of total area) in microbial bioluminescence tests performed with solvent extracts of sediments from 18 U. S. bays and estuaries.

Survey areas	Year sampled	No. of sediment samples	Total area of survey (km^2)	Microbial bioluminescence* Toxic area (km^2)	Microbial bioluminescence* Pct. of area toxic
Choctawhatchee Bay	94	37	254.47	254.5	100.0%
St. Andrew Bay	93	31	127.2	127	100.0%
Apalachicola Bay	94	9	187.6	186.8	99.6%
Pensacola Bay	93	40	273	262.8	96.4%
Galveston Bay	96	75	1351.1	1143.7	84.6%
Sabine Lake	95	66	245.9	194.2	79.0%
Winyah Bay	93	9	7.3	5.13	70.0%
Long Island Sound	91	60	71.86	48.8	67.9%
Savannah River	94	60	13.12	7.49	57.1%
Biscayne Bay	95/96	226	484.2	248.4	51.3%
St. Simons Sound	94	20	24.6	11.4	46.4%
Boston Harbor	93	55	56.1	25.8	44.9%
Charleston Harbor	93	63	41.1	17.6	42.9%
Hudson-Raritan Estuary	91	117	350	136.1	38.9%
Leadenwah Creek	93	9	1.69	0.34	20.1%
Delaware Bay[A]	97	73	2346.8	114	4.9%
northern Puget Sound [A]	97	100	773.9	17.7	2.2%
southern Puget Sound[A]	99	100	857.7	1.5	0.2%
Tampa Bay	92/93	165	550	0.6	0.1%
central Puget Sound [A]	98	100	731.7	0	0.0%
Cumulative National estuarine average based upon data collected through:					
•1997		1215	7160	2802.4	39.1%

[A] Critical value of <0.51 mg/mL

* Critical value of <80% of control

Table 37. Spatial extent of toxicity (km^2 and percentages of total area) in cytochrome P450 HRGS tests performed with solvent extracts of sediments from 8 U. S. bays and estuaries.

Survey areas	Year sampled	No. of sediment samples	Total area of survey (km^2)	Cytochrome P450 HRGS (>11.1 μg/g) Toxic area (km^2)	Cytochrome P450 HRGS (>11.1 μg/g) Pct. of area toxic	Cytochrome P450 HRGS (>37.1 μg/g) Toxic area (km^2)	Cytochrome P450 HRGS (>37.1 μg/g) Pct. of area toxic
northern Chesapeake Bay	1998	63	2265.0	1127.3	49.8	633.9	28.0
southern Puget Sound	1999	100	857.7	329.2	38.4	43.1	5.0
Delaware Bay	1997	73	2346.8	145.2	6.2	80.5	3.4
central Puget Sound	1998	100	731.7	237.1	32.4	23.7	3.2
Sabine Lake	1995	65	245.9	6.7	2.7	1.7	0.7
northern Puget Sound	1997	100	806.2	20.1	2.5	0.2	0.0
Southern Cal. Estuaries	1994	30	5.0	2.3	46.8	0.0	0.0
Biscayne Bay, 1996	1996	121	271.4	8.8	3.3	0.0	0.0
Galveston Bay	1996	75	1351.5	56.7	4.2	0.0	0.0
Cumulative National estuarine averages based upon data collected through:							
•1997		627	8023.5	1604.2	20.0	740	9.2

Table 38. Estimated spatial extent of chemical contamination in three regions of Puget Sound and in the entire survey area as measured with three sets of critical values. The number and % of stations and the number and % of the total study area (km^2) are calculated for those stations where at least one chemical was measured at levels above state criteria and/or NOAA guidelines (excluding data for nickel.) (Shaded area = total number of stations and area of each region)

Sediment Guideline or Criteria Exceeded	No. (%) of stations		km^2	(%) of total study area
1997 Northern Puget Sound	**100**	**(100.0)**	**773.9**	**(100.0)**
ERM	9	(9.0)	9.5	(1.2)
SQS	71	(71.0)	529.8	(68.5)
CSL	58	(58.0)	434.3	(56.1)
Total for any one guideline or criteria exceeded	71	(71.0)	529.8	(68.5)
1998 Central Puget Sound	**100**	**(100.0)**	**731.7**	**(100.0)**
ERM	21	(21.0)	11.4	(1.6)
SQS	93	(93.0)	669.0	(91.4)
CSL	92	(92.0)	667.9	(91.3)
Total for any one guideline or criteria exceeded	93	(93.0)	669.0	(91.4)
1999 Southern Puget Sound	**100**	**(100.0)**	**857.7**	**(100.0)**
ERM	9	(9.0)	9.9	(1.2)
SQS	17	(17.0)	57.2	(6.7)
CSL	10	(10.0)	44.2	(5.1)
Total for any one guideline or criteria exceeded	20	(20.0)	60.7	(7.1)
Total Study Area	**300**	**(100.0)**	**2363.3**	**(100.0)**
ERM	39	(13.0)	30.7	(1.3)
SQS	181	(60.3)	1256.0	(53.1)
CSL	160	(53.3)	1146.3	(48.5)
Total for any one guideline or criteria exceeded	184	(61.3)	1259.5	(53.3)

Table 39. Percentages of Puget Sound study areas with indices of degraded sediments based upon the sediment quality triad of data. (Shaded area = total number of stations and area of each region)

Sediment Quality Index Category (number of parameters impaired /station)	No. (%) of stations		km^2	(%) of total study area
1997 Northern Puget Sound	**100**	**(100.0)**	**773.9**	**(100.0)**
High (0)	26	(26.0)	211.9	(27.4)
Intermediate/High (1)	52	(52.0)	516.2	(66.7)
Intermediate/Degraded (2)	12	(12.0)	35.5	(4.6)
Degraded (3)	10	(10.0)	10.3	(1.3)
1998 Central Puget Sound	**100**	**(100.0)**	**731.7**	**(100.0)**
High (0)	2	(2.0)	59.5	(8.1)
Intermediate/High (1)	38	(38.0)	436.1	(59.6)
Intermediate/Degraded (2)	39	(39.0)	215.7	(29.5)
Degraded (3)	21	(21.0)	20.4	(2.8)
1999 Southern Puget Sound	**100**	**(100.0)**	**857.7**	**(100.0)**
High (0)	36	(36.0)	493.5	(57.5)
Intermediate/High (1)	35	(35.0)	274.1	(32.0)
Intermediate/Degraded (2)	18	(18.0)	85.7	(10.0)
Degraded (3)	11	(11.0)	4.4	(0.5)
Total Study Area	**300**	**(100.0)**	**2363.3**	**(100.0)**
High (0)	64	(21.3)	764.9	(32.4)
Intermediate/High (1)	125	(41.7)	1226.4	(51.9)
Intermediate/Degraded (2)	69	(23.0)	336.8	(14.3)
Degraded (3)	42	(14.0)	35.1	(1.5)

High - (no parameter impaired)
Intermediate/High - (one parameter impaired chemistry, toxicity, or benthos)
Intermediate/Degraded - (two parameters impaired chemistry, toxicity, or benthos)
Degraded - (three parameters impaired chemistry, toxicity, or benthos)

Appendix A

Historical surveys previously conducted in the 1999 southern Puget Sound study area from which the data were archived in the SEDQUAL database.

Appendix A. Historical surveys previously conducted in the 1999 southern Puget Sound study area from which the data were archived in the SEDQUAL database.

Agency Name	Survey Name	Beginning date	Ending date	Chief Scientist
Anchor Cove Condominium Association.	Anchor Cove Condominium Marina Project.	7/16/90	12/18/90	D. Kendall (Corps)
Army Corps of Engineers	Kenmore Navigational Channel, Lk. Wash.	7/1/85	7/31/85	J. W. Anderson
	Oak Harbor Marine Expansion Project	2/26/85	2/26/85	J.W. Anderson
	Port Garnder Quality Criteria	3/17/86	3/20/86	E.A. Crecelius
Battelle, Pacific Northwest Labs,	South Puget Sound Toxicants In Sediments	8/1/82	8/1/82	Robert G. Riley
Beak Consultants, Inc.	98 Bremerton Wtp NPDES Sed. Mon. Report	4/28/98	4/29/98	Gerald M. Erickson
	LOTT 1996 NPDES Sed. Monitoring Report	5/29/96	5/31/96	David B. Hericks
Cascade Pole Co./Port of Olympia/Ecology	Cascade Pole Remedial Investigation.	12/6/90	8/14/91	Mark Herrenkohl
CH2MHILL	Boise Cascades West Tacoma Mill Baseline	9/28/95	9/28/95	David Wilson
	Post Point Treatm Plant, B'Ham Cty, 1996	4/29/96	5/1/96	D. Wilson
Chevron Oil USA, Inc.	Chevron USA Edmonds Dock Maint.	1/31/90	1/31/90	D. Kendall (Corps)
City of Dupont/Ecology	91 City of Dupont DEIS Sediment Analysis	5/13/91	5/13/91	Cliff Whitmus
City of Olympia\Lott	1992 LOTT Budd Inlet Sample Study	3/4/92	3/4/92	Asha Mhatre
City of Renton / Golder Associates	Cedar River Delta Sediment Sampling	3/9/92	3/12/92	Golder Associates
City of Tacoma/Public Works Dept	Olympic View Restoration In Commencement	1/11/99	7/30/99	O'Loughlin, John

Appendix A. Continued.

Agency Name	Survey Name	Beginning date	Ending date	Chief Scientist
COE	Morton Marine Maintenance Dredging	9/15/91	9/18/91	D. Kendall (Corps)
Conestoga-Rovers & Associates	Occidental Chem. Co.'S Sed. From Hy	6/5/89	6/9/89	Liam D. Antrim
Corps of Engineers/Port of Bellingham.	Maint./Other Dredging of Bellingham Bay.	11/13/90	5/9/91	D. Kendall (Corps)
Ecochem, Inc.	Scott Paper Co. Baseline Sediment Survey	5/1/95	5/9/95	Tom Belnick
Ensr	Gp Baseline Sed. Character., '93 NPDES	9/8/93	9/10/93	Bill Conbere
	Aluminum Company of America, Vancouver	9/20/93	9/22/93	Bill Conbere
Geo Engineers, Inc.	U.S. Navy Pier D Supplemental Sampling	8/10/93	8/13/93	Sally Fisher
Hart Crowser, Inc.	Eagle Harbor Predesign Sediment Sampling	6/29/94	11/5/94	
	Lonestar Nw Sediment Character. Rpt, 94	1/18/94	1/18/94	Mike Ehlebrach
	Middle Waterway Tideflat Sediments	6/2/92	6/2/92	
	Whatcom Waterway 1996 RI Report	4/23/96	9/26/97	
Hurlen Construction Co., Seattle	Hurlen Construction Co. Maint. Dredging.	5/11/90	5/11/90	D. Kendall (Corps)
King County	Denny Way Cap Monitoring 1994-96	6/15/94	9/11/96	Wilson And Romberg
	Duwamish Yacht Club Marina Maint. Dredge	11/29/88	11/29/88	D. Kendall (Corps)
	Norfolk Cso Sediment Cleanup Study 1,2,3	8/17/94	12/6/95	Scott Mickelson
	West Point Ebo Baseline Study Phase 1	2/1/96	9/25/96	Scott Mickelson
Metropolitan Seattle	1984 Duwamish Head Survey	1/1/84	1/1/84	
	Metro NPDES & Ambient Subtidal Monitor.	8/21/90	8/23/90	Pat Romberg

Appendix A. Continued.

Agency Name	Survey Name	Beginning date	Ending date	Chief Scientist
	Metro NPDES & Ambient Subtidal Monitor.	8/31/92	9/1/92	Pat Romberg
	Metro NPDES & Ambient Subtidal Monitor.	9/7/88	9/7/88	Pat Romberg
	Seahurst Baseline Study	7/1/82	2/1/84	A. Nevissi
	TPPS Phase III A & B	3/4/81	10/1/82	
	Westpoint Emergency Bypass Outfall.	10/13/89	10/24/89	D. Kendall (Corps)
National Oceanic And Atmospheric Administration	1980 NOAA OMPA-19 Survey of Elliott Bay.	1/1/79	9/1/80	
	Benthic Surveillance 1985	8/12/85	8/15/85	Bruce Mccain
	Benthic Surveillance 1986	5/1/86	6/19/86	Bruce Mccain
	Benthic Surveillance 1989	5/16/89	5/18/89	Bruce Mccain
	Central Puget Sound Data, Misc. Sources	7/1/75	12/1/83	Malins,Krahn,Bates
	Comm. Bay Prelim. Rifs, Bioaccum/Pathol	6/4/84	6/8/84	Bruce Mccain
	Dissolved Trace Metals In Puget Sound	5/1/80	8/1/81	Paulson, A.J.
	N. Puget Sound Survey, NOAA OMPA-7	6/1/78	1/1/79	Donald W. Brown
	Noaa Chinook Salmon Bioaccum. Study	5/23/89	6/28/90	Usha Varanasi
	NOAA Nat'l Status & Trends Mussel Watch	11/18/87	1/27/88	Thomas O'Connor
	NOAA Nat'l Status & Trends Mussel Watch	12/12/86	2/23/87	Thomas O'Connor
	NOAA Nat'l Status & Trends Mussel Watch	1/7/86	3/17/86	Thomas O'Connor
	NOAA Recreational Fish Bioaccum. Study	3/28/84	10/15/85	Marcia Landolt
	NOAA'l Duwamish River Study	5/1/86	6/20/86	
	NRDA Sed. Svy of Comm & Elliott Bays	5/23/94	6/17/94	Robert C. Clark
	Olympia Harbor Planning, Full Character.	11/8/88	11/14/88	U. Varanasi
	Pacific Marine Center Sediment Survey	6/30/94	6/30/94	
One Tree Island Marina	One Tree Island (Fiddlehead) Marina Proj	1/29/85	5/23/85	
Parametrix, Inc.	Chambers Creek Wwtp Marine Sediment	11/6/95	11/7/95	

Appendix A. Continued.

Agency Name	Survey Name	Beginning date	Ending date	Chief Scientist
	Pope and Talbot - Port Gamble 1	3/6/00	3/8/00	Jennifer Hawkins
	Salmon Bay Phase III	5/19/97	5/21/97	
	Sound Refining Npdes Sediment Monitoring	4/7/92	4/7/92	
	St. Paul Waterway Area Remedial Action	6/14/93	7/19/93	Parametric, Inc.
Port of Everett	Everett 12Th St. Barge Channel Dredging.	2/1/92	3/14/92	Dennis Gregoire
	Everett Harbor 10Th St. Boat Ramp Expan.	10/25/91	12/3/91	Dennis Gregoire
	Everett Marina Maintenance Dredging.	7/19/88	7/19/88	Dennis Gregoire
Port of Olympia	Olympia Har. Berth 2 Sediment Study.	4/8/85	4/8/85	Dick Malin
	Olympia Har. Berth 3 Reconstr. Dredging.	12/16/86	12/16/86	Richard Malin
Port of Seattle	American President's Line Maint. Dredge	3/30/92	4/13/92	D. Kendall (Corps)
	Study At North End of Terminal 5	12/20/84	12/20/84	
	Terminal 5 W. Waterway Maint. Dredging	6/14/91	6/19/91	Doug Hotchkiss
	Terminal 91, W. Side Apron Construction	11/5/91	11/11/91	Doug Hothckiss
Port of Silverdale/Us Army Corps-Seattle	Port of Silverdale Dock/Pier/Ramp Dredge	1/22/91	1/22/91	D. Kendall (Corps)
Port of Tacoma	Port of Tacoma RI/NRDA (Sitc/Mlwk/Blair)	8/23/91	9/10/91	
	Port of Tacoma, Blair Waterway Project	1/1/91	2/8/91	D. Kendall (Corps)
	West Blair Term. Dev Verif Samplg Rep.	4/13/94	4/13/94	Mike Ehlebracht
	Puyallup Land Settlement: Blair, Hylebos	1/10/90	1/28/91	Landau Associates
PTI Environmental Services	PSDAA Phase I Survey of Disposal Sites	5/6/88	6/11/88	Paula Ehlers
	PSDDA Phase 2 Survey of Disposal Sites	4/14/89	5/6/89	Paula Ehlers
	Puget Sound Reference Areas Survey	6/19/90	6/26/90	D. Scott Becker
	Weyerhauser Everett, Wa	3/28/94	4/1/94	

Appendix A. Continued.

Agency Name	Survey Name	Beginning date	Ending date	Chief Scientist
Puget Sound Ambient Monitoring	PSAMPTrawl Data For 1989	4/1/89	4/1/89	
	PSAMP Trawl Data For 1991	5/1/91	5/1/91	
	PSAMP Trawl Data For 1992	5/1/92	5/1/92	
SAIC	Sediment Characterization At PSNS	1/11/99	2/4/99	
Striplin Environmnetal Associates	PSDDA's Konoike-Pacific Termnls On Blair	2/22/93	2/22/93	Betsy Striplin
Sweet-Edwards/Emcon Northwest, Inc.	General Metals of Tacoma, Inc	1/7/91	1/19/91	Bruce Mcalister
Tetra Tech, Inc.	Elliott Bay Fish Pathology Survey.	9/16/85	9/20/85	
Thurston County Health Department	Indian/Moxlie Cr. (Olympis) Basin Samp.	2/24/92	2/24/92	S. Berg/C. Hansen
	Olympia/West Bay Marina Sampling.	8/21/91	8/21/91	Claire Mcelreath
U.S. Army Corps of Engineers	Day Island Yacht Club (Tacoma) Character	6/11/91	6/11/91	D. Kendall
	Duwamish R. Maintenance Dredge, Phase 1	8/28/90	10/3/90	D. Fox (Corps)
	Duwamish R. Maintenance Dredge, Phase 2	8/6/91	9/9/91	D. Fox (Corps)
	Duwamish R. Maintenance Dredging Project	4/18/89	1/19/90	D. Kendall (Corps)
	Log Raft/Chip Barge Area, Port Gamble.	12/28/88	12/29/88	D. Kendall (Corps)
	Lonestar Northwest - West Terminal	5/29/92	6/3/92	D. Kendall (Corps)
	LOTT Olympia Treat. Plant Outfall, DY89	10/31/89	10/31/89	D. Kendall (Corps)
	LOTT Olympia Treat. Plant Outfall, DY91	10/3/91	11/16/91	D. Kendall (Corps)
	PSDDA Duwamish River I Data Set.	4/15/85	4/19/85	S.-L. Chan
	PSDDA Duwamish River II Data Set.	7/1/85	7/1/85	S.-L. Chan
	South Park Marina Maint. Dredging, 1991	9/14/91	9/18/91	D. Kendall (Corps)

Appendix A. Continued.

Agency Name	Survey Name	Beginning date	Ending date	Chief Scientist
	U.S. Navy Bremerton Pier D	3/25/91	12/27/91	Peter Havens (Usn)
	Upper Duwamish, Neah And Clallam Bays	9/1/84	9/1/84	
U.S. Coast Guard	US Coast Guard Dredging And Construction	9/19/89	9/19/89	D. Kendall (Corps)
U.S. EPA And Ecology	Bellingham/Mukilteo Storm Drain Sampling	9/17/90	9/20/90	M.A. Jacobson
U.S. EPA Region 10	1985 Elliott Bay Sediment Survey	9/25/85	10/16/85	
	1985 Everett Hbr. Fish Survey.	8/25/86	9/2/86	
	1990 Supplementary Marine Sed. Survey	8/1/89	8/1/89	
	ASARCO Remedial Investigation - Round 1	10/1/87	10/1/87	
	ASARCO Remedial Investigation - Round 2	7/1/88	7/1/88	
	ASARCO Supplementary Marine Sed. Survey	10/1/90	10/1/90	
	Commencement Bay Feasibility Study	5/20/86	5/20/86	
	Dioxins In Puget Sound Crabs	3/11/91	4/11/91	
	EPA Wa Natural Gas - Seattle Plant	11/29/94	1/27/95	David Bennett
	PS Sediments For Bioassay Comparisons	5/1/88	5/1/88	
	Puget Sound Reconnaissance Survey - Spri	4/19/88	5/28/88	Eric Crecelius
	Sitcum W. Remed. Project Phase 1 Area	4/5/94	4/6/94	Port of Tacoma
	Sitcum W. Remed. Project Phase 2 Area	4/13/94	4/13/94	Port of Tacoma
	Sitcum's Milwaukee Waterway Habitat Area	4/6/94	4/6/94	Port of Tacoma
	South Puget Sound Reconaissance Survey	4/3/90	5/2/90	D. Scott Becker
U.S. EPA Region 10, Dept. of Social & Health Services	Dept. of Health Shellfish Bioaccum Study	4/24/86	8/11/87	Jacques Faigenblum
U.S. EPA Region 10, Surveillance & Analysis	Chemistry/Biology of Liberty Bay	9/16/75	9/16/75	J.M. Cummins

Appendix A. Continued.

Agency Name	Survey Name	Beginning date	Ending date	Chief Scientist
U.S. EPA Region 10/Hylebos Cleanup Committee	Hylebos Waterway Prd Event 1A, 1B & 1C	6/27/94	7/18/96	Striplin Env. Assc
U.S. Navy	Data From EIS For Navy Home-Port Project	1/1/85	1/1/85	
	Everett Homeport (Full Characterization)	3/7/89	4/24/89	D. Kendall (Corps)
	U.S. Navy Bangor KB Dock	1/14/92	1/14/92	D. Kendall (Corps)
	U.S. Navy Bangor TRF Drydock Dredge	2/7/92	4/7/92	S. Stirling, Corps
	US Navy Manchester Fuel Pier Replacement	3/27/89	4/12/89	Joseph Divittorio
University of Washington	Metals In Puget Sound Sediments 1970-72	1/1/72	1/1/72	Eric A. Crecelius
	PAH In Puget Sound Sediments	1/1/76	1/1/76	R.C. Barrick
	Puget Sound & Strait Juan de Fuca Grain Size	6/19/50	3/1/73	Richard W. Roberts
URS Consultants	Sinclair Inlet Monitoring, 1994	3/16/94	7/14/94	
	The Navy's Keyport RI Report	8/12/89	9/17/92	
US EPA (Weston Prime; Pti Sub)	Harbor Island Phase II RI	9/24/91	10/31/91	Chip Hogue
US Oil Refining Company	US Oil Refinery Blair Ww Maint. Dredging	11/9/89	4/20/90	D. Kendall (Corps)
USACE	Blair Bridge, Port of Tacoma, 1994	10/4/94	10/4/94	
	Bremerton, City of, Warren Avenue Cso	4/13/93	6/1/93	
	Everett, US Navy Norton Terminal, Dy94	1/1/93	3/9/93	
	Grays Harbor, Port of, O&M, Dy94	1/1/94	2/8/94	
	Grays Harbor, Port of, Terminal 2, Dy94	2/2/94	2/8/94	
	Grays Harbor, Port of, Terminal 4, Dy94	5/13/93	5/13/93	
	Port of Seattle Terminal5 Pier Extension	6/14/94	8/6/94	
	PSDDA Report: '93 Des Moines Marina	9/28/93	9/29/93	

Appendix A. Continued.

Agency Name	Survey Name	Beginning date	Ending date	Chief Scientist
	PSDDA Report: Indian Cove Moorage, Dy94	3/29/93	5/5/93	
	PSDDA Report:Brownsville Marina, Port of	4/26/93	4/26/93	
	Simpson Tacoma, Middle Waterway Restora	2/25/94	2/25/94	
	Squalicum Waterway Sediment Characterizn	1/1/01	1/18/95	
	Tacoma, Port of, West Blair Development	11/3/93	11/5/93	
Washington Department of Ecology	Boise Cascade's West Tacoma Mill Class 2	4/22/89	4/22/89	Don Reif
	Budd Inlet	6/9/98	6/10/98	Dale Norton
	Chevron Point Wells Terminal 95	4/16/95	5/31/95	Jay Spearman
	Colman Dock - South Area, Seattle, Wa	1/1/93	8/8/94	Hart Crowser
	Commencement Bay Nat.Res. Assessment	3/26/94	5/31/94	P.Sparks
	Commencement Bay RI Main Sed. Qual. Sur.	1/1/84	3/11/84	
	Commencement Bay RI Prelim. Survey 1984	3/1/84	3/1/84	
	Commencmnt Bay RI Blair Waterway Dredge	6/1/84	6/1/84	
	Contaminant Flux To City Waterway 1990	11/9/88	11/9/88	Dale Norton
	Duwamish Shipyard, Elliot Bay, Wa	8/18/93	8/18/93	Hart Crowser
	Duwamish Waterway Dy 93	9/1/96	9/29/96	P. Sparks
	Early Mcfarland Cascade Sediment Study.	2/13/85	8/14/85	Dale Norton
	Edmonds WTP Class II Inspection	4/17/89	4/17/89	Jeanne Andreasson
	EILS' Thea Foss Water Way Sampling	1/12/89	12/5/91	Dale Norton
	Everett Simpson Site Sediment Investigat	6/21/94	6/21/94	Teresa Michelson
	Hansville Landfill Site Hazard Assessmnt	5/31/91	6/5/91	Elaine Atkinson
	Harbor Island Supp Remedial Invest	3/10/95	3/23/95	Pam Sparks-Mckonky
	Hylebos Waterway-Striplin 1994	7/1/94	8/1/94	P. Sparks
	Lockheed Sediment Data, 1991 and 1994	5/28/91	1/27/94	Mclaren Hart
	McNeil Island Sediment Quality & Biaccum	4/18/88	4/18/88	Dale Norton
	Methylphenol In Log Rafting Areas of Cb	2/11/87	2/11/87	Dale Norton
	Navy Everett Terminal Norton Dy 1994	2/8/93	3/9/93	P. Sparks

Appendix A. Continued.

Agency Name	Survey Name	Beginning date	Ending date	Chief Scientist
	Neanthes Sublethal Test Demo.	10/1/88	10/1/88	P.Sparks
	North Duwamish Waterway	1/9/92	1/9/92	Hart Crowser
	NW Enviroservices Offsite Investigation	4/12/94	4/12/94	Ch2Mhill
	Olympus Terrace WTP Class II Inspection	3/19/92	3/28/92	Steven Golding
	PAH In Sediments Near Wyckoff Facility	4/21/88	4/21/88	James C. Cubbage
	PCB Contamination In Hylebos Waterway.	7/21/86	7/23/86	Margaret Stinson
	Pennwalt Class II Inspection Report	4/5/88	4/5/88	Marc Heffner
	Port of Seattle Terminal 18 Phase I	3/1/96	6/12/96	P. Sparks
	Port of Seattle Terminal 18 Phase II	5/30/96	6/12/96	P.Sparks
	Port of Seattle, T30 Apron Rehab Project	6/17/93	7/28/93	Parametrix, Inc.
	Port Seattle Terminal 5 Pier Extension	6/14/94	6/14/94	Parametrix
	PSAMP Sediment Monitoring 1990	1/1/90	12/31/90	
	PSAMP Sediment Monitoring 1991	1/1/91	12/31/91	
	PSAMP Sediment Monitoring 1992	1/1/92	12/31/92	
	PSAMP Sediment Monitoring 1993	1/1/93	12/31/93	
	PSAMP Sediment Monitoring 1994	1/1/94	12/31/94	
	PSAMP Sediment Monitoring 1995	1/1/95	12/31/95	
	PSEP Harbor Seal Study (On Liver Tissue)	7/4/90	9/13/90	
	Quartermaster Harbor: Dockton Sediments	2/3/86	2/3/86	Bill Yake
	Seattle Steel Mill, 1989	9/11/89	9/11/89	Wa Dept of Ecology
	Sitcum Waterway 1990-91 Monitoring	1/21/91	1/21/91	Dale Norton
	South Cap Seattle Ferry Terminal	8/10/94	8/15/94	Ch2MHill
	Tacoma Central WTP Class II Inspection	6/28/89	6/28/89	Jeanne Andreasson
	Todd Shipyard Sediment Monitoring Data	12/13/93	12/14/93	Landau Assoc.
	USACE Everett Downstream Settling Basin	12/10/92	1/28/93	P. Sparks
	Weyer 056	1/1/92	1/1/92	P.Sparks

Appendix A. Concluded.

Agency Name	Survey Name	Beginning date	Ending date	Chief Scientist
Washington Department of Natural Resources	1990 PSDDA Post-Disposal Site Monitoring	5/15/90	7/19/90	Gene Revelas
	1992 PSDDA Full Monitoring, Elliott Bay	6/11/92	6/19/92	Gene Revelas
	Aq. Lands Sediment Qual. Reconnaissance.	1/20/92	1/25/92	Phil Herzog
	Aq. Lands Sediment Qual. Reconnaissance.	2/8/91	2/13/91	B. Striplin
	PSDDA 1991 Monitoring/Port Gardner Pgb09	6/3/91	6/6/91	
Washington Dept. of Fisheries	Rockfish Monitoring Survey, Fall 1989	10/5/89	11/2/89	O'Neill & Schmitt
	Rockfish Monitoring Survey, Fall 1991	10/30/91	1/8/92	O'Neill & Schmitt
WWU,NOAA,OSU	Misc. PS Reference Area Grain Size	11/23/81	7/1/87	Dewitt,Broad,Chapm
Wyckoff Company	Wyckoff Effluent Investigation: 1St Qtr.	4/23/90	4/23/90	J. Fegley/Att
	Wyckoff Effluent Investigation: 2Nd Qtr.	7/27/90	7/27/90	J. Fegley/Att
	Wyckoff Effluent Investigation: 3Rd Qtr.	10/19/90	10/19/90	J. Fegley/Att
Unknown	1985 Puget Sound Eight-Bay Survey.	8/6/83	5/29/84	
Unknown	US Navy Bremerton Pier D, Round 2, DY94	8/9/93	9/24/93	

Appendix B

Detected chemicals from southern Puget Sound SEDQUAL sediment samples exceeding Washington State Sediment Quality Standards (SQS) and Cleanup Screening Levels (CSL).

Appendix B. Detected chemicals from southern Puget Sound sediment samples in the SEDQUAL database exceeding Washington State Sediment Quality Standards (SQS) and Puget Sound Marine Sediment Cleanup Screening Levels (CSL).

Chemical Contaminant	SQS Sample location (No. of samples)	SQS value	CSL Sample location (No. of samples)	CSL value
1,2,4-Trichlorobenzene	Blair Waterway (6), Budd Inlet (1), Commencement Bay (2), Hylebos Waterway (46), Milwaukee Waterway (10), Sitcum Waterway (7)	0.81 (ppm oc)	Blair Waterway (2), Budd Inlet (1), Commencement Bay (2), Hylebos Waterway (16), Milwaukee Waterway (2), Sitcum Waterway (6)	1.8 (ppm oc)
1,2-Dichlorobenzene	Blair Waterway (2), Commencement Bay (2), Hylebos Waterway (1), Thea Foss Waterway (1)	2.3 (ppm oc)	Blair Waterway (2), Commencement Bay (1), Hylebos Waterway (1), Thea Foss Waterway (1)	2.3 (ppm oc)
1,4-Dichloro-benzene	Blair Waterway (6), Commencement Bay (2), Hylebos Waterway (16), Sitcum Waterway (1) Thea Foss Waterway (2)	3.1 (ppm oc)	Blair Waterway (1), Commencement Bay (1), Hylebos Waterway (3)	9 (ppm oc)
2,4-Dimethylphenol	Blair Waterway (15), Budd Inlet (1), Commencement Bay (14), Hylebos Waterway (5), Milwaukee Waterway (3), Thea Foss Waterway (3)	29 (ppb)	Blair Waterway (15), Budd Inlet (1), Commencement Bay (14), Hylebos Waterway (4), Milwaukee Waterway (2), Thea Foss Waterway (3)	29 (ppb)
2-Methyl-naphthalene	Blair Waterway (4), Budd Inlet (9), Commencement Bay (5), Hylebos Waterway (8), Milwaukee Waterway (1), Sitcum Waterway (5)	38 (ppm oc)	Blair Waterway (2), Budd Inlet (7), Commencement Bay (2), Hylebos Waterway (4), Milwaukee Waterway (1), Sitcum Waterway (1)	64 (ppm oc)
2-Methylphenol	Blair Waterway (9), Budd Inlet (3), Commencement Bay (3), Hylebos Waterway (2), Middle Waterway (1), Milwaukee Waterway (2), Thea Foss Waterway (2)	63 (ppb)	Blair Waterway (9), Budd Inlet (3), Commencement Bay (3), Hylebos Waterway (2), Middle Waterway (1), Milwaukee Waterway (2), Thea Foss Waterway (2)	63 (ppb)
4-Methylphenol	Budd Inlet (1), Carr Inlet (2), Commencement Bay (4), Thea Foss Waterway (2)	670 (ppb)	Budd Inlet (1), Carr Inlet (2), Commencement Bay (4), Thea Foss Waterway (2)	670 (ppb)

Appendix B. Continued.

Chemical Contaminant	SQS Sample location (No. of samples)	SQS value	CSL Sample location (No. of samples)	CSL value
Acenaphthene	Blair Waterway (7), Budd Inlet (32), Commencement Bay (9), Hylebos Waterway (19), Middle Waterway (1), Milwaukee Waterway (2), Sitcum Waterway (10), Steilacoom (1), Thea Foss Waterway (1)	16 (ppm oc)	Budd Inlet (21), Commencement Bay (4), Hylebos Waterway (3), Milwaukee Waterway (2), Sitcum Waterway (3), Steilacoom (1)	57 (ppm oc)
Acenaphthylene	Budd Inlet (2), Gig Harbor (1)	66 (ppm oc)	Budd Inlet (2), Gig Harbor (1)	66 (ppm oc)
Anthracene	Blair Waterway (1), Budd Inlet (11), Commecement Bay (2), Hylebos Waterway (4), Steilacoom (1)	220 (ppm oc)	Budd Inlet (2)	1200 (ppm oc)
Arsenic	Blair Waterway (13), Commencement Bay (161), Hylebos Waterway (56), Middle Waterway (1), Milwaukee Waterway (1), Sitcum Waterway (21)	57 (ppm)	Blair Waterway (3), Commencement Bay (91), Hylebos Waterway (33), Sitcum Waterway (15)	93 (ppm)
Benzo(a) anthracene	Blair Waterway (4), Budd Inlet (13), Commencement Bay (4), Gig Harbor (1), Hylebos Waterway (11), Milwaukee Waterway (3), Sitcum Waterway (4), Steilacoom (1), Thea Foss Waterway (2)	110 (ppm oc)	Blair Waterway (2), Budd Inlet (5), Commencement Bay (1), Hylebos Waterway (2), Sitcum Waterway (2)	270 (ppm oc)
Benzo(a) pyrene	Blair Waterway (5), Budd Inlet (7), Commencement Bay (3), Gig Harbor (1), Hylebos Waterway (13), Milwaukee Waterway (1), Sitcum Waterway (8), Steilacoom (1), Thea Foss Waterway (1)	99 (ppm oc)	Blair Waterway (1), Budd Inlet (3), Commencement Bay (1), Hylebos Waterway (1), Sitcum Waterway (2)	210 (ppm oc)

Appendix B. Continued.

Chemical Contaminant	SQS Sample location (No. of samples)	SQS value	CSL Sample location (No. of samples)	CSL value
Benzo(g,h,i) perylene	Blair Waterway (7), Budd Inlet (8), Commencement Bay (4), Gig Harbor (1), Hylebos Waterway (13), Milwaukee Waterway (2), Sitcum Waterway (14), Steilacoom (1), Thea Foss Waterway (2)	31 (ppm oc)	Blair Waterway (1), Budd Inlet (4), Commencement Bay (1), Gig Harbor (1), Hylebos Waterway (2), Sitcum Waterway (7), Thea Foss Waterway (1)	78 (ppm oc)
Benzoic acid	Blair Waterway (2), Commencement Bay (1), Hylebos Waterway (3), Thea Foss Waterway (2)	650 (ppb)	Blair Waterway (2), Commencement Bay (1), Hylebos Waterway (3), Thea Foss Waterway (2)	650 (ppb)
Benzyl alcohol	Budd Inlet (1), Commecement Bay (6), Hylebos Waterway (9), Sitcum Waterway (1), Thea Foss Waterway (2)	57 (ppb)	Budd Inlet (1), Commecement Bay (6), Hylebos Waterway (5), Sitcum Waterway (1), Thea Foss Waterway (2)	73 (ppb)
Bis(2-ethylhexyl) phthalate	Blair Waterway (9), Budd Inlet (4), Commencement Bay (10), Hylebos Waterway (17), Milwaukee Waterway (3), Sitcum Waterway (21), Thea Foss Waterway (9)	47 (ppm oc)	Blair Waterway (5), Budd Inlet (4), Commencement Bay (9), Hylebos Waterway (10), Milwaukee Waterway (2), Sitcum Waterway (14), Thea Foss Waterway (6)	78 (ppm oc)
Butyl benzyl phthalate	Blair Waterway (5), Budd Inlet (1), Commencement Bay (6), Hylebos Waterway (14), Milwaukee Waterway (1), Sitcum Waterway (5), Thea Foss Waterway (6)	4.9 (ppm oc)	Commencement Bay (1), Hylebos Waterway (2), Thea Foss Waterway (1)	64 (ppm oc)
Cadmium	Blair Waterway (1), Budd Inlet (2), Carr Inlet (1), Commencement Bay (13), Hylebos Waterway (2), Milwaukee Waterway (2), Sitcum Waterway (15), Thea Foss Waterway (6)	5.1 (ppm)	Blair Waterway (1), Budd Inlet (2), Carr Inlet (1), Commencement Bay (12), Hylebos Waterway (2), Milwaukee Waterway (2), Sitcum Waterway (9), Thea Foss Waterway (1)	6.7 (ppm)
Chromium	Budd Inlet (1), Hylebos Waterway (2)	260 (ppm)	Budd Inlet (1), Hylebos Waterway (2)	270 (ppm)

Appendix B. Continued.

Chemical Contaminant	SQS Sample location (No. of samples)	SQS value	CSL Sample location (No. of samples)	CSL value
Chrysene	Blair Waterway (11), Budd Inlet (14), Commencement Bay (4), Gig Harbor (1), Hylebos Waterway (20), Milwaukee Waterway (4), Sitcum Waterway (8), Steilacoom (1), Thea Foss Waterway (3)	110 (ppm oc)	Blair Waterway (3), Budd Inlet (4), Hylebos Waterway (2), Milwaukee Waterway (1)	460 (ppm oc)
Copper	Blair Waterway (4), Budd Inlet (1), Commecement Bay (115), Hylebos Waterway (20), Middle Waterway (1), Milwaukee Waterway (1), Sitcum Waterway (12)	390 (ppm)	Blair Waterway (4), Budd Inlet (1), Commecement Bay (115), Hylebos Waterway (20), Middle Waterway (1), Milwaukee Waterway (1), Sitcum Waterway (12)	390 (ppm)
Dibenz(a,h) anthracene	Blair Waterway (12), Budd Inlet (5), Commencement Bay (3), Gig Harbor (1), Hylebos Waterway (24), Milwaukee Waterway (3), Sitcum Waterway (13), Steilacoom (1), Thea Foss Waterway (5)	12 (ppm oc)	Blair Waterway (1), Budd Inlet (1), Commencement Bay (2), Hylebos Waterway (3), Sitcum Waterway (7), Steilacoom (1), Thea Foss Waterway (1)	33 (ppm oc)
Dibenzofuran	Blair Waterway (5), Budd Inlet (23), Commencement Bay (10), Hylebos Waterway (14), Milwaukee Waterway (2), Sitcum Waterway (5), Steilacoom (1)	15 (ppm oc)	Budd Inlet (13), Commencement Bay (1), Hylebos Waterway (1), Milwaukee Waterway (1), Sitcum Waterway (1), Steilacoom (1)	58 (ppm oc)
Diethyl phthalate	Commecement Bay (1)	61 (ppm oc)	Commecement Bay (1)	110 (ppm oc)
Dimethyl phthalate	Sitcum Waterway (2)	53 (ppm oc)	Sitcum Waterway (2)	53 (ppm oc)
Di-n-butyl phthalate	Commecement Bay (3), Thea Foss Waterway (1)	220 (ppm oc)	Thea Foss Waterway (1)	1700 (ppm oc)
Di-n-octyl phthalate	Hylebos Waterway (1), Thea Foss Waterway (1)	58 (ppm oc)	Hylebos Waterway (1), Thea Foss Waterway (1)	4500 (ppm oc)

Appendix B. Continued.

Chemical Contaminant	SQS Sample location (No. of samples)	SQS value	CSL Sample location (No. of samples)	CSL value
Fluoranthene	Blair Waterway (7), Budd Inlet (20), Commencement Bay (6), Gig Harbor (1), Hylebos Waterway (15), Milwaukee Waterway (2), Sitcum Waterway (8), Steilacoom (1), Thea Foss Waterway (2)	160 (ppm oc)	Budd Inlet (5)	1200 (ppm oc)
Fluorene	Blair Waterway (5), Budd Inlet (28), Commencement Bay (10), Gig Harbor (1), Hylebos Waterway (16), Milwaukee Waterway (2), Sitcum Waterway (5), Steilacoom (1), Thea Foss Waterway (2)	23 (ppm oc)	Budd Inlet (14), Commencement Bay (2), Hylebos Waterway (4), Milwaukee Waterway (2), Steilacoom (1)	79 (ppm oc)
Hexachloro-benzene	Blair Waterway (18), Budd Inlet (1), Commencement Bay (5), Hylebos Waterway (97), Milwaukee Waterway (13), Sitcum Waterway (6)	0.38 (ppm oc)	Blair Waterway (3), Budd Inlet (1), Commencement Bay (1), Hylebos Waterway (39), Milwaukee Waterway (5), Sitcum Waterway (4)	2.3 (ppm oc)
Hexachloro-butadiene	Blair Waterway (2), Hylebos Waterway (41), Milwaukee Waterway (10), Sitcum Waterway (5)	3.9 (ppm oc)	Hylebos Waterway (26), Milwaukee Waterway (3), Sitcum Waterway (4)	6.2 (ppm oc)
High Molecular Weight PAH	Blair Waterway (7), Budd Inlet (12), Commencement Bay (4), Gig Harbor (1), Hylebos Waterway (14), Milwaukee Waterway (3), Sitcum Waterway (8), Steilacoom (1), Thea Foss Waterway (2)	960 (ppm oc)	Budd Inlet (4)	5300 (ppm oc)
Indeno (1,2,3-cd) pyrene	Blair Waterway (10), Budd Inlet (8), Commencement Bay (3), Gig Harbor (1), Hylebos Waterway (19), Milwaukee Waterway (2), Sitcum Waterway (14), Steilacoom (1), Thea Foss Waterway (3)	34 (ppm oc)	Blair Waterway (3), Budd Inlet (3), Commencement Bay (1), Gig Harbor (1), Hylebos Waterway (3), Milwaukee Waterway (1), Sitcum Waterway (6), Thea Foss Waterway (1)	88 (ppm oc)

Appendix B. Continued.

Chemical Contaminant	SQS Sample location (No. of samples)	SQS value	CSL Sample location (No. of samples)	CSL value
Lead	Blair Waterway (4), Commecement Bay (113), Hylebos Waterway (14), Milwaukee Waterway (2), Sitcum Waterway (20), Thea Foss Waterway (8)	450 (ppm)	Blair Waterway (1), Commecement Bay (61), Hylebos Waterway (13), Milwaukee Waterway (2), Sitcum Waterway (18), Thea Foss Waterway (5)	530 (ppm)
Low Molecular Weight PAH	Blair Waterway (5), Budd Inlet (19), Commencement Bay (7), Gig Harbor (1), Hylebos Waterway (11), Milwaukee Waterway (2), Sitcum Waterway (3), Steilacoom (1), Thea Foss Waterway (2)	370 (ppm oc)	Blair Waterway (1), Budd Inlet (12), Commencement Bay (2), Hylebos Waterway (4), Milwaukee Waterway (2), Sitcum Waterway (1)	780 (ppm oc)
Mercury	Blair Waterway (36), Commecement Bay (39), Hylebos Waterway (74), Middle Waterway (7), Milwaukee Waterway (12), Sitcum Waterway (51), Thea Foss Waterway (12)	0.41 (ppm)	Blair Waterway (16), Commecement Bay (24), Hylebos Waterway (41), Middle Waterway (7), Milwaukee Waterway (9), Sitcum Waterway (47), Thea Foss Waterway (10)	0.59 (ppm)
Naphthalene	Budd Inlet (23), Commecement Bay (4), Hylebos Waterway (4), Milwaukee Waterway (1)	99 (ppm oc)	Budd Inlet (13), Commecement Bay (2), Hylebos Waterway (2), Milwaukee Waterway (1)	170 (ppm oc)
N-Nitroso diphenylamine	Commecement Bay (2)	11 (ppm oc)	Commecement Bay (2)	11 (ppm oc)
Penta-chlorophenol	Blair Wateray (3), Hylebos Waterway (2), Middle Waterway (1), Sitcum Waterway (1)	360 (ppb)	Blair Wateray (3), Hylebos Waterway (2)	690 (ppb)
Phenanthrene	Blair Waterway (9), Budd Inlet (19), Commencement Bay (8), Gig Harbor (1), Hylebos Waterway (16), Milwaukee Waterway (3), Sitcum Waterway (8), Steilacoom (1), Thea Foss Waterway (4)	100 (ppm oc)	Blair Waterway (1), Budd Inlet (10), Commencement Bay (1), Hylebos Waterway (2), Milwaukee Waterway (2), Sitcum Waterway (1)	480 (ppm oc)

Appendix B. Concluded.

Chemical Contaminant	SQS Sample location (No. of samples)	SQS value	CSL Sample location (No. of samples)	CSL value
Phenol	Carr Inlet (1), Commencement Bay (3), Hylebos Waterway (6), Middle Waterway (1), Milwaukee Waterway (1), Thea Foss Waterway (1)	420 (ppb)	Carr Inlet (1), Commencement Bay (1), Hylebos Waterway (1), Milwaukee Waterway (1)	1200 (ppb)
Pyrene	Blair Waterway (1), Budd Inlet (5), Hylebos Waterway (1)	1000 (ppm oc)	Budd Inlet (4), Hylebos Waterway (1)	1400 (ppm oc)
Silver	Blair Waterway (1), Commencement Bay (7), Sitcum Waterway (18)	6.1 (ppm)	Blair Waterway (1), Commencement Bay (7), Sitcum Waterway (18)	6.1 (ppm)
Total benzo-fluoranthenes (b+k (+j))	Blair Waterway (6), Budd Inlet (6), Commencement Bay (3), Gig Harbor (1), Hylebos Waterway (11), Milwaukee Waterway (1), Sitcum Waterway (6), Steilacoom (1), Thea Foss Waterway (1)	230 (ppm oc)	Blair Waterway (3), Budd Inlet (4), Commencement Bay (1), Hylebos Waterway (3), Sitcum Waterway (2)	450 (ppm oc)
Total Poly-chlorinated Biphenyls	Blair Waterway (6), Commencement Bay (11), Hylebos Waterway (59), Milwaukee Waterway (11), North of Devils Head (1), Sitcum Waterway (41), Steilacoom (2)	12 (ppm oc)	Blair Waterway (6), Commencement Bay (2), Hylebos Waterway (10), Milwaukee Waterway (4), North of Devils Head (1), Sitcum Waterway (12), Steilacoom (2)	65 (ppm oc)
Zinc	Blair Waterway (7), Budd Inlet (1), Commencement Bay (123), Hylebos Waterway (27), Milwaukee Waterway (3), Sitcum Waterway (28), Thea Foss Waterway (3)	410 (ppm)	Blair Waterway (1), Commencement Bay (65), Hylebos Waterway (14), Milwaukee Waterway (2), Sitcum Waterway (13)	960 (ppm)

Appendix C

Navigation report for the 1999 southern Puget Sound sampling stations.

Appendix C. Navigation report for the 1999 southern Puget Sound sampling stations.

Stratum	Sample	Station	Deploy-ment No.	Date	GPS Time	GPS PDOP/HDOP	Stern Transd. Depth m.	Predicted Tide (m.): Nearest Station	Predicted Mudline Depth, m. (MLLW)	Distance to Station (m)	LORAN-C Yankee	LORAN-C Zulu	DGPS (Trimble NT300D) NAD 1983 Decimal Minutes Latitude	DGPS (Trimble NT300D) NAD 1983 Decimal Minutes Longitude	Station Target NAD 1983 Decimal Minutes Latitude	Station Target NAD 1983 Decimal Minutes Longitude	Van Veen Grab Type
Location																	
01	**206**	1	1		1342	2..2/1.1	17.0	1.7	-15.3	0.4	28227.7	42276.0	47 55.3063	122 40.6082			
Port Ludlow			2	25-Jun-99	1354	2.2/1.1	17.1	1.8	-15.3	0.2	28227.8	42276.1	47 55.3062	122 40.6080	47 55.3063	122 40.6079	heavy VV
			3		1413	2.0/1.2	17.5	2.0	-15.5	0.4	28227.7	42276.0	47 55.3059	122 40.6078			
01	**207**	2	1		1648	2.1/1.4	14.5	2.4	-12.1	1.1	28229.6	42276.0	47 55.4679	122 40.7700			
Port Ludlow			2	24-Jun-99	1659	2.1/1.4	14.5	2.4	-12.1	1.0	28229.6	42275.9	47 55.4689	122 40.7703	47 55.4684	122 40.7705	heaviest VV
			3		1709	2.1/1.4	15.0	2.4	-12.6	0.9	28229.7	42276.0	47 55.4689	122 40.7704			
			4		1715	2.0/1.4	14.7	2.4	-12.3	0.7	28229.6	42275.9	47 55.4687	122 40.7707			
01	**208**	3	1		1518	1.9/1.0	5.5	2.4	-3.1	0.2	28226.0	42274.8	47 54.9999	122 40.8296			
Port Ludlow			2		1532	2.0/1.1	5.5	2.4	-3.1	1.3	28226.0	42274.6	47 54.9999	122 40.8308			
			3	24-Jun-99	1545	2.4/1.2	5.5	2.4	-3.1	1.0	28226.0	42274.7	47 55.0004	122 40.8292	47 55.0000	122 40.8296	heaviest VV
			4		1555	2.3/1.2	5.5	2.4	-3.1	0.7	28226.1	42274.7	47 55.0002	122 40.8298			
			5		1608	2.3/1.2	5.5	2.4	-3.1	0.8	28226.0	42274.7	47 55.0003	122 40.8292			
02	**209**	1--2	1		1323	2.1/1.1	78.0	1.9	-76.1	0.6	28180.2	42272.6	47 50.4619	122 38.7563			
Hood Canal (North)			2	24-Jun-99	1337	2.2/1.1	78.0	2.0	-76.0	0.7	28180.2	42272.6	47 50.4617	122 38.7568	47 50.4616	122 38.7563	heaviest VV
			3		1350	2.2/1.1	78.5	2.1	-76.4	1.8	28180.1	42272.6	47 50.4612	122 38.7577			
			4		1403	2.1/1.1	79.0	2.2	-76.8	0.6	28180.2	42272.7	47 50.4618	122 38.7566			
02	**210**	2	1		1218	1..8/0.9	39.7	1.3	-38.4	1.4	28185.2	42270.1	47 50.6700	122 39.6699			
Hood Canal (North)			2	24-Jun-99	1233	2.2/1.1	40.0	1.5	-38.5	0.7	28185.2	42270.1	47 50.6706	122 39.6711	47 50.6702	122 39.6710	heaviest VV
			3		1245	2.6/1.2	39.5	1.6	-37.9	0.2	28185.3	42270.1	47 50.6703	122 39.6711			
			4		1256	2.7/1.3	39.5	1.7	-37.8	0.5	28185.2	42270.1	47 50.6703	122 39.6714			
02	**211**	3	1		0938	1.8/1.0	111.5	0.2	-111.3	0.8	28231.6	42285.1	47 56.6334	122 38.5536			
Hood Canal (North)			2		1010	2.2/1.2	111.5	0.3	-111.2	2.0	28231.6	42285.1	47 56.6342	122 38.5518			
			3	24-Jun-99	1024	2.2/1.2	112.0	0.4	-111.6	1.1	28231.6	42285.1	47 56.6336	122 38.5521	47 56.6335	122 38.5530	heavy VV
			4		1035	2.2/1.1	112.0	0.5	-111.5	2.9	28231.6	42285.1	47 56.6327	122 38.5509			
			5		1056	1.8/1.0	111.5	0.6	-110.9	1.2	28231.6	42285.1	47 56.6337	122 38.5537			
			6		1111	1.7/0.9	112.0	0.7	-111.3	1.3	28231.6	42285.2	47 56.6327	122 38.5523			
03	**212**	1--3	1		0949	1.7/1.0	14.0	0.0	-14.0	1.1	28165.0	42286.4	47 50.6345	122 34.3765			
Port Gamble Bay			2	25-Jun-99	1001	1.7/1.0	14.0	0.0	-14.0	1.2	28165.0	42286.4	47 50.6345	122 34.3777	47 50.6340	122 34.3770	heavy VV
			3		1011	2.3/1.2	14.0	0.0	-14.0	0.9	28165.0	42286.5	47 50.6343	122 34.3775			
			4		1020	2.2/1.2	14.1	0.1	-14.0	0.6	28165.0	42286.4	47 50.6338	122 34.3774			
03	**213**	2	1		1047	2.1/1.1	4.5	0.1	-4.4	0.8	28154.8	42283.7	47 49.3379	122 34.5359			
Port Gamble Bay			2	25-Jun-99	1057	2.8/1.5	4.7	0.2	-4.5	0.8	28154.8	42283.6	47 49.3377	122 34.5367	47 49.3381	122 34.5365	heavy VV
			3		1107	1.7/0.9	4.7	0.3	-4.4	0.3	28154.8	42283.7	47 49.3382	122 34.5367			
			4		1115	1.7/0.9	4.8	0.3	-4.5	0.3	28154.8	42283.7	47 49.3380	122 34.5363			

Appendix C. Continued.

Stratum	Sample	Station	Deployment No.	Date	GPS Time	GPS PDOP/HDOP	Stern Transd. Depth m.	Predicted Tide (m.): Nearest Station	Predicted Mudline Depth, m. (MLLW)	Distance to Station (m)	LORAN-C Yankee	LORAN-C Zulu	DGPS (Trimble NT300D) NAD 1983 Decimal Minutes Latitude	DGPS (Trimble NT300D) NAD 1983 Decimal Minutes Longitude	Station Target NAD 1983 Decimal Minutes Latitude	Station Target NAD 1983 Decimal Minutes Longitude	Van Veen Grab Type
03	**214**	3--2	1		1147	1.7/1.0	12.2	0.6	-11.6	0.9	28162.4	42284.6	47 50.1775	122 34.7111			
Port Gamble Bay			2	25-Jun-99	1158	1.8/0.9	12.3	0.6	-11.7	0.8	28162.4	42284.7	47 50.1777	122 34.7108	47 50.1776	122 34.7104	heavy VV
			3		1209	1.8/0.9	12.3	0.7	-11.6	1.4	28162.4	42284.7	47 50.1773	122 34.7093			
04	**215**	1	1		1024	2.2/1.1	14.8	-0.2	-15.0	1.9	28206.3	42227.6	47 47.9473	122 51.4184			
Quilcene Bay			2	28-Jun-99	1036	2.1/1.1	14.4	-0.3	-14.7	0.2	28206.2	42227.6	47 47.9481	122 51.4192	47 47.9482	122 51.4191	heavy VV
			3		1043	2.0/1.1	14.7	-0.3	-15.0	0.2	28206.3	42227.7	47 47.9481	122 51.4192			
04	**216**	2	1		1108	1.7/0.9	16.2	-0.4	-16.6	0.6	28205.6	42227.3	47 47.8279	122 51.5182			
Quilcene Bay			2	28-Jun-99	1118	2.1/1.1	16.2	-0.4	-16.6	0.8	28205.7	42227.3	47 47.8273	122 51.5188	47 47.8276	122 51.5183	lightest VV
			3		1127	1.7/1.0	16.2	-0.4	-16.6	0.5	28205.6	42227.2	47 47.8275	122 51.5186			
04	**217**	3	1		1304	2.1/1.1	27.2	0.0	-27.2	0.6	28201.6	42227.1	47 47.4054	122 51.3196			
Quilcene Bay			2	28-Jun-99	1315	2.2/1.1	27.3	0.1	-27.2	1.1	28201.6	42227.1	47 47.4066	122 51.3196	47 47.4055	122 51.3201	heavy VV
			3		1324	2.2/1.1	27.3	0.2	-27.1	0.8	28201.6	42227.1	47 47.4058	122 51.3205			
05	**218**	1	1		1416	3.6/2.1	61.0	0.9	-60.1	0.9	28207.8	42237.2	47 49.2345	122 49.1035			
Dabob Bay			2	28-Jun-99	1426	3.8/2.3	61.0	1.0	-60.0	1.0	28207.8	42237.3	47 49.2355	122 49.1038	47 49.2351	122 49.1038	heavy VV
			3		1435	1.8/1.0	61.0	1.1	-59.9	1.1	28207.8	42237.2	47 49.2346	122 49.1028			
05	**219**	2	1		1000	2.2/1.2	171.0	0.3	-170.7	0.9	28171.1	42222.4	47 43.8030	122 50.9516			
Dabob Bay			2	29-Jun-99	1021	2.2/1.1	171.0	0.1	-170.9	0.7	28171.1	42222.4	47 43.8032	122 50.9511	47 43.8027	122 50.9510	lightest VV
			3		1033	2.1/1.1	171.0	0.0	-171.0	0.3	28171.1	42222.5	47 43.8025	122 50.9508			
05	**220**	3	1		1109	2.1/1.1	175.0	-0.3	-175.3	0.2	28172.3	42223.9	47 44.0791	122 50.6446			
Dabob Bay			2	29-Jun-99	1127	1.7/1.0	175.0	-0.4	-175.4	0.3	28172.3	42223.9	47 44.0792	122 50.6444	47 44.0792	122 50.6447	lightest VV
			3		1140	1.8/0.9	175.0	-0.4	-175.4	0.8	28172.3	42223.9	47 44.0794	122 50.6454			
06	**221**	1	1		1000	2.2/1.2	120.0	0.8	-119.2	0.5	28090.3	42143.6	47 25.2380	123 06.6198			
Hood Canal (central)			2	30-Jun-99	1013	2.2/1.1	120.0	0.7	-119.3	0.9	28090.4	42143.7	47 25.2383	123 06.6188	47 25.2380	123 06.6194	lightest VV
			3		1024	2.1/1.1	120.0	0.6	-119.4	0.8	28090.3	42143.6	47 25.2375	123 06.6193			
06	**222**	2	1		1256	2.0/1.1	120.0	-0.3	-120.3	2.0	28138.6	42223.4	47 40.6933	122 48.8806			
Hood Canal (central)			2	29-Jun-99	1319	2.1/1.1	120.5	-0.2	-120.7	1.0	28138.6	42223.3	47 40.6924	122 48.8795	47 40.6926	122 48.8794	lightest VV
			3		1331	2.2/1.1	120.5	-0.1	-120.6	1.1	28138.6	42223.4	47 40.6928	122 48.8787			
06	**223**	3	1		1418	4.0/2.3	166.0	0.4	-165.6	1.9	28136.3	42205.1	47 38.0933	122 53.4508			
Hood Canal (central)			2	29-Jun-99	1434	1.8/1.0	166.5	0.7	-165.8	0.5	28136.3	42205.1	47 38.0944	122 53.4508	47 38.0941	122 53.4517	lightest VV
			3		1449	1.9/1.0	166.7	0.9	-165.8	1.0	28136.3	42205.1	47 38.0935	122 53.4512			
07	**224**	1	1		1237	2.7/1.4	21.5	-0.5	-22.0	0.6	28039.4	42172.4	47 23.4444	122 56.3850			
Hood Canal (South)			2	30-Jun-99	1250	2.5/1.5	21.5	-0.5	-22.0	0.5	28039.4	42172.6	47 23.4443	122 56.3855	47 23.4445	122 56.3855	lightest VV
			3		1259	2.1/1.1	21.5	-0.5	-22.0	0.5	28039.5	42172.6	47 23.4443	122 56.3856			
07	**225**	2	1		1320	2.2/1.1	19.2	-0.4	-19.6	0.5	28045.2	42170.1	47 23.7925	122 57.3611			
Hood Canal (South)			2	30-Jun-99	1331	2.2/1.1	19.3	-0.4	-19.7	0.4	28045.3	42170.1	47 23.7921	122 57.3608	47 23.7924	122 57.3607	lightest VV
			3		1340	2.1/1.1	19.4	-0.3	-19.7	1.1	28045.1	42169.9	47 23.7925	122 57.3598			

Appendix C. Continued.

Stratum	Sample	Station	Location	Deployment No.	Date	GPS Time	GPS PDOP/HDOP	Stern Transd. Depth m.	Predicted Tide (m.): Nearest Station	Predicted Mudline Depth, m. (MLLW)	Distance to Station (m)	LORAN-C Yankee	LORAN-C Zulu	DGPS (Trimble NT300D) NAD 1983 Decimal Minutes Latitude	DGPS (Trimble NT300D) NAD 1983 Decimal Minutes Longitude	Station Target NAD 1983 Decimal Minutes Latitude	Station Target NAD 1983 Decimal Minutes Longitude	Van Veen Grab Type
07	**226**	3	Hood Canal (South)	1	30-Jun-99	1056	1.7/0.9	87.0	0.1	-86.9	0.9	28076.7	42136.2	47 22.6786	123 07.7477	47 22.6791	123 07.7475	lightest VV
				2		1111	2.1/1.1	87.0	0.0	-87.0	0.5	28076.8	42136.3	47 22.6793	123 07.7473			
				3		1121	1.7/1.0	86.5	-0.1	-86.6	1.5	28076.8	42136.3	47 22.6793	123 07.7464			
08	**227**	1--2	Port of Shelton	1	10-Jun-99	1406	2.5/1.5	4.7	1.9	-2.8	2.2	28000.4	42131.3	47 12.7540	123 05.0441	47 12.7526	123 05.0440	heavy VV
				2		1419	2.1/1.1	5.0	2.2	-2.8	1.1	28000.4	42131.2	47 12.7529	123 05.0447			
				3		1429	2.2/1.1	5.2	2.4	-2.8	1.1	28000.4	42131.4	47 12.7529	123 05.0448			
				4		1437	2.2/1.1	5.3	2.5	-2.8	0.7	28000.4	42131.1	47 12.7529	123 05.0442			
08	**228**	2	Port of Shelton	1	10-Jun-99	1255	1.8/0.9	2.6	1.0	-1.6	1.6	27999.1	42131.3	47 12.5826	123 04.9685	47 12.5834	123 04.9680	heavy VV
				2		1303	1.8/0.9	2.6	1.1	-1.5	0.2	27999.1	42131.3	47 12.5834	123 04.9681			
				3		1311	1.8/0.9	2.7	1.2	-1.5	0.5	27999.1	42131.3	47 12.5837	123 04.9680			
				4		1320	1.8/0.9	2.8	1.3	-1.5	1.3	27999.2	42131.3	47 12.5841	123 04.9677			
08	**229**	3	Port of Shelton	1	10-Jun-99	1101	2.4/1.3	2.5	0.1	-2.4	0.2	28000.3	42131.4	47 12.7416	123 05.0349	47 12.7415	123 05.0350	heavy VV
				2		1114	1.7/1.0	2.2	0.1	-2.1	1.2	28000.3	42131.3	47 12.7409	123 05.0346			
				3		1123	2..2/1.2	2.1	0.1	-2.0	1.9	28000.3	42131.3	47 12.7405	123 05.0347			
				4		1139	1.1/1.9	2.3	0.2	-2.1	1.2	28000.3	42131.3	47 12.7413	123 05.0341			
09	**230**	1--2	Oakland Bay	1	10-Jun-99	0907	2.0/1.1	6.0	0.8	-5.2	0.4	27998.0	42131.8	47 12.5266	123 04.7566	47 12.5267	123 04.7564	heavy VV
				2		0917	1.9/1.1	5.9	0.7	-5.2	0.7	27998.0	42132.0	47 12.5266	123 04.7559			
				3		0924	2.0/1.2	5.9	0.6	-5.3	0.9	27998.0	42131.9	47 12.5268	123 04.7570			
				4		0932	1.5/0.9	5.7	0.5	-5.2	1.5	27998.0	42131.9	47 12.5262	123 04.7555			
09	**231**	2--5	Oakland Bay	1	10-Jun-99	1536	4.0/2.3	6.6	3.2	-3.4	1.6	27998.6	42135.8	47 13.1665	123 03.7783	47 13.1674	123 03.7783	light VV
				2		1545	4.0/2.4	6.8	3.3	-3.5	1.0	27998.6	42135.7	47 13.1680	123 03.7785			
				3		1556	1.8/1.0	6.9	3.4	-3.5	0.4	27998.6	42135.8	47 13.1675	123 03.7780			
09	**232**	3	Oakland Bay	1	10-Jun-99	1015	1.8/1.0	3.5	0.2	-3.3	0.3	27998.7	42136.1	47 13.2407	123 03.6891	47 13.2406	123 03.6894	heavy VV
				2		1028	1.8/1.0	3.4	0.1	-3.3	1.0	27998.8	42136.2	47 13.2404	123 03.6887			
				3		1035	1.8/1.0	3.4	0.1	-3.3	0.7	27998.8	42136.2	47 13.2404	123 03.6897			
10	**233**	1	Totten Inlet	1	7-Jun-99	1349	2.5/1.2	7.9	2.6	-5.3	1.4	27960.2	42141.2	47 09.3173	123 00.2620	47 09.3178	123 00.2629	light VV
				2		1408	2.7/1.4	7.8	2.5	-5.3	2.2	27960.1	42141.2	47 09.3172	123 00.2641			
				3		1416	3.2/1.7	7.7	2.4	-5.3	1.7	27960.2	42141.3	47 09.3180	123 00.2616			
10	**234**	2--2	Totten Inlet	1	7-Jun-99	1707	2.3/1.2	2.4	1.0	-1.4	1.4	27953.7	42132.3	47 06.9593	123 02.3078	47 06.9598	123 02.3086	light VV
				2		1717	2.4/1.2	2.4	1.0	-1.4	0.0	27953.7	42132.2	47 06.9598	123 02.3086			
				3		1725	1.9/1.1	2.3	0.9	-1.4	1.6	27953.7	42132.1	47 06.9591	123 02.3080			
10	**235**	3	Totten Inlet	1	7-Jun-99	1442	2.2/1.1	10.2	2.2	-8.0	2.2	27953.4	42145.8	47 09.1917	122 58.6502	47 09.1915	122 58.6520	light VV
				2		1455	2.2/1.1	10.1	2.1	-8.0	0.9	27953.4	42145.8	47 09.1916	122 58.6512			
				3		1504	2.2/1.1	10.0	2.0	-8.0	0.6	27953.4	42145.8	47 09.1914	122 58.6517			
				4		1512	2.1/1.1	10.0	2.0	-8.0	1.4	27953.4	42145.8	47 09.1919	122 58.6511			

Appendix C. Continued.

Stratum	Sample	Station	Deploy-ment No.	Date	GPS Time	GPS PDOP/HDOP	Stern Transd. Depth m.	Predicted Tide (m.): Nearest Station	Predicted Mudline Depth, m. (MLLW)	Distance to Station (m)	LORAN-C Yankee	LORAN-C Zulu	DGPS (Trimble NT300D) NAD 1983 Decimal Minutes Latitude	DGPS Longitude	Station Target NAD 1983 Decimal Minutes Latitude	Station Target Longitude	Van Veen Grab Type
11	**238**	1	1		1002	2.1/1.2	12.5	2.3	-10.2	1.0	27933.9	42146.4	47 06.7959	122 57.4229			
Eld Inlet			2	7-Jun-99	1020	1.5/0.9	12.7	2.4	-10.3	1.9	27933.9	42146.3	47 06.7974	122 57.4221	47 06.7964	122 57.4226	light VV
			3		1031	1.8/1.0	12.8	2.5	-10.3	1.0	27933.9	42146.4	47 06.7969	122 57.4225			
11	**239**	2	1		1100	1.8/1.0	12.6	2.7	-9.9	0.1	27937.8	42146.3	47 07.3304	122 57.6254			
Eld Inlet			2	7-Jun-99	1113	1.7/1.0	12.7	2.8	-9.9	1.0	27937.8	42146.4	47 07.3309	122 57.6249	47 07.3304	122 57.6253	light VV
			3		1123	1.8/1.1	12.7	2.8	-9.9	1.1	27937.8	42146.4	47 07.3299	122 57.6257			
11	**240**	3	1		1200	2.1/1.1	7.5	2.9	-4.6	0.4	27934.1	42141.1	47 05.9624	122 58.8212			
Eld Inlet			2	7-Jun-99	1214	2.8/1..5	7.5	2.9	-4.6	1.1	27934.1	42141.1	47 05.9624	122 58.8199	47 05.9624	122 58.8208	light VV
			3		1221	1.7/0.9	7.5	2.9	-4.6	0.6	27934.1	42141.1	47 05.9624	122 58.8203			
12	**236**	1	1		0918	2.0/1.1	8.1	1.2	-6.9	0.1	27920.4	42156.9	47 06.8542	122 53.8172			
Budd Inlet			2	8-Jun-99	0933	2.0/1.1	8.3	1.3	-7.0	0.3	27920.4	42156.9	47 06.8541	122 53.8168	47 06.8542	122 53.8171	light VV
			3		0945	1.5/0.9	8.4	1.4	-7.0	0.8	27920.3	42156.9	47 06.8539	122 53.8166			
12	**237**	2	1		1022	1.6/01.9	13.1	1.7	-11.4	0.6	27929.9	42155.3	47 07.7561	122 54.8271			
Budd Inlet			2	8-Jun-99	1037	1.8/1.0	13.3	1.8	-11.5	0.8	27929.9	42155.1	47 07.7567	122 54.8268	47 07.7563	122 54.8269	light VV
			3		1049	1.8/1.0	13.4	1.9	-11.5	0.3	27929.8	42155.3	47 07.7563	122 54.8267			
12	**241**	3	1		1124	1.7/1.0	13.5	2.3	-11.2	0.3	27932.3	42155.7	47 08.1280	122 54.8697			
Budd Inlet			2	8-Jun-99	1139	2.2/1.1	13.5	2.4	-11.1	0.9	27932.3	42155.5	47 08.1279	122 54.8706	47 08.1278	122 54.8698	light VV
			3		1148	2.2/1.1	13.7	2.5	-11.2	1.0	27932.3	42155.6	47 08.1281	122 54.8691			
13	**242**	1--2	1		1531	2.0/1.2	5.5	2.6	-2.9	1.1	27898.3	42152.0	47 03.1717	122 53.8417			
Port of Olympia			2	8-Jun-99	1543	3.6/2.2	5.5	2.6	-2.9	1.2	27898.2	42152.0	47 03.1717	122 53.8417	47 03.1717	122 53.8417	light VV
			3		1552	3.9/2.4	5.5	2.5	-3.0	0.2	27898.2	42152.1	47 03.1717	122 53.8417			
13	**243**	2	1		1415	2.5/1.5	6.5	3.0	-3.5	0.6	27897.4	42152.2	47 03.0983	122 53.7533			
Port of Olympia			2	8-Jun-99	1430	2.1/1.1	6.5	3.0	-3.5	0.4	27897.4	42152.1	47 03.0983	122 53.7533	47 03.0983	122 53.7533	light VV
			3		1439	2.2/1.1	6.5	2.9	-3.6	0.2	27897.4	42152.2	47 03.0983	122 53.7533			
			4		1448	2.2/1.1	6.4	2.9	-3.5	1.2	27897.4	42152.2	47 03.0983	122 53.7533			
13	**244**	3	1		1322	1.8/0.9	4.6	3.0	-1.6	2.6	27902.6	42150.4	47 03.4504	122 54.5480			
Port of Olympia			2	8-Jun-99	1331	1.7/0.9	4.6	3.0	-1.6	0.7	27902.6	42150.4	47 03.4504	122 54.5501	47 03.4500	122 54.5500	light VV
			3		1349	2.6/1.9	4.6	3.0	-1.6	0.7	27902.6	42150.4	47 03.4497	122 54.5500			
14	**245**	1	1		1315	1.8/0.9	13.1	2.7	-10.4	0.8	27980.7	42165.0	47 15.4994	122 55.1507			
Pickering Passage/Squaxin			2	9-Jun-99	1326	1.9/1.1	13.1	2.8	-10.3	0.8	27980.8	42164.8	47 15.5001	122 55.1505	47 15.4997	122 55.1501	heavy VV
Island			3		1335	2.2/1.1	13.0	2.9	-10.1	1.7	27980.7	42164.8	47 15.4988	122 55.1498			
14	**246**	2--2	1		1202	2.4/1.5	30.9	1.9	-29.0	0.4	27982.6	42181.3	47 18.2274	122 50.9956			
Pickering Passage/Squaxin			2	9-Jun-99	1218	1.7/0.9	31.1	2.1	-29.0	2.8	27982.6	42181.3	47 18.2257	122 50.9954	47 18.2273	122 50.9954	heavy VV
Island			3		1229	2.1/1.2	31.3	2.2	-29.1	1.1	27982.6	42181.4	47 18.2270	122 50.9947			

Appendix C. Continued.

Stratum / Location	Sample	Station	Deployment No.	Date	GPS Time	GPS PDOP/HDOP	Stern Transd. Depth m.	Predicted Tide (m.): Nearest Station	Predicted Mudline Depth, m. (MLLW)	Distance to Station (m)	LORAN-C Yankee	LORAN-C Zulu	DGPS (Trimble NT300D) NAD 1983 Decimal Minutes Latitude	DGPS Longitude	Station Target NAD 1983 Decimal Minutes Latitude	Station Target Longitude	Van Veen Grab Type
14	**247**	3	1	9-Jun-99	0900	2.2/1.2	20.2	0.6	-19.6	0.9	27941.8	42159.8	47 10.0215	122 54.3072	47 10.0216	122 54.3079	heavy VV
Pickering Passage/Squaxin Island			2		0915	2.0/1.1	20.2	0.6	-19.6	0.8	27941.8	42159.9	47 10.0217	122 54.3086			
			3		0924	1.9/1.1	20.3	0.6	-19.7	1.0	27941.8	42159.9	47 10.0220	122 54.3071			
			4		0935	1.8/1.1	20.3	0.7	-19.6	0.9	27941.7	42159.9	47 10.0218	122 54.3085			
15	**248**	1	1	4-Jun-99	1105	1.8/1.0	9.0	2.5	-6.5	1.9	27916.4	42170.1	47 08.5717	122 50.1308	47 08.5717	122 50.1324	light VV
Henderson Inlet			2		1114	1.8/1.0	9.0	2.4	-6.6	0.1	27916.4	42170.2	47 08.5716	122 50.1324			
			3		1122	1.7/1.0	9.0	2.4	-6.6	1.4	27916.4	42170.1	47 08.5724	122 50.1319			
15	**249**	2	1	4-Jun-99	1343	1.8/0.9	5.8	0.8	-5.0	1.2	27913.5	42169.5	47 08.1035	122 50.1469	47 08.1040	122 50.1473	light VV
Henderson Inlet			2		1354	1.7/0.9	5.7	0.7	-5.0	0.9	27913.6	42169.6	47 08.1037	122 50.1467			
			3		1401	2.3/1.1	5.7	0.6	-5.1	0.8	27913.5	42169.5	47 08.1039	122 50.1467			
15	**250**	3	1	4-Jun-99	1247	1.7/0.9	7.2	1.4	-5.8	1.0	27918.3	42169.2	47 08.6703	122 50.4781	47 08.6698	122 50.4779	light VV
Henderson Inlet			2		1301	1.7/0.9	7.1	1.3	-5.8	0.9	27918.3	42169.3	47 08.6693	122 50.4776			
			3		1311	1.7/1.0	7.0	1.1	-5.9	1.5	27918.3	42169.3	47 08.6705	122 50.4773			
			4		1321	1.8/0.9	6.9	1.0	-5.9	0.6	27918.3	42169.3	47 08.6697	122 50.4775			
16	**251**	1	1	3-Jun-99	1331	1.8/0.9	60.0	0.3	-59.7	0.7	27933.8	42178.2	47 12.0103	122 48.9854	47 12.0105	122 48.9859	light VV
Case Inlet			2		1345	1.8/0.9	60.0	0.1	-59.9	1.5	27933.8	42178.3	47 12.0097	122 48.9861			
			3		1358	1.7/0.9	60.0	0.0	-60.0	1.6	27933.8	42178.2	47 12.0100	122 48.9869			
16	**252**	2	1	3-Jun-99	1043	2.0/1.3	55.0	2.3	-52.7	0.2	27969.3	42178.4	47 16.1742	122 51.0605	47 16.1741	122 51.0604	light VV
Case Inlet			2		1058	2.1/1.3	54.5	2.1	-52.4	0.8	27969.4	42178.3	47 16.1742	122 51.0610			
			3		1118	2.2/1.2	54.5	1.9	-52.6	2.8	27969.3	42178.3	47 16.1736	122 51.0583			
16	**253**	3	1	3-Jun-99	1153	2.2/1.2	45.0	1.4	-43.6	2.0	27946.6	42176.8	47 13.2910	122 50.1109	47 13.2916	122 50.1095	light VV
Case Inlet			2		1204	2.2/1.1	45.0	1.3	-43.7	2.1	27946.6	42176.9	47 13.2904	122 50.1083			
			3		1215	2.1/1.1	45.0	1.2	-43.8	2.6	27946.6	42176.9	47 13.2906	122 50.1080			
17	**254**	1	1	2-Jun-99	1105	1.8/1.0	63.0	1.5	-61.5	1.1	27895.2	42184.6	47 08.4193	122 45.0657	47 08.4188	122 45.0653	heavy VV
Nisqually Reach			2		1126	1.7/1.0	63.0	1.3	-61.7	1.6	27895.2	42184.6	47 08.4193	122 45.0644			
			3		1137	1.7/1.0	62.5	1.1	-61.4	2.1	27895.2	42184.5	47 08.4182	122 45.0668			
17	**255**	2	1	2-Jun-99	1403	1.7/0.9	86.0	-0.3	-86.3	1.2	27918.7	42181.4	47 10.7947	122 47.2422	47 10.7949	122 47.2433	heavy VV
Nisqually Reach			2		1416	2.6/1.3	86.0	-0.4	-86.4	1.2	27918.8	42181.4	47 10.7942	122 47.2430			
			3		1426	3.2/1.7	87.0	-0.4	-87.4	3.6	27918.7	42181.5	47 10.7934	122 47.2415			
			4		0949	2.1/1.2	90.0	2.9	-87.1	2.2	27918.7	42181.4	47 10.7945	122 47.2449			
17	**256**	3	1	2-Jun-99	1249	1.7/0.9	70.0	0.2	-69.8	1.6	27903.6	42181.1	47 08.8887	122 46.4541	47 08.8895	122 46.4537	heavy VV
Nisqually Reach			2		1304	2.1/1.2	70.0	0.1	-69.9	2.5	27903.7	42181.1	47 08.8880	122 46.4532			
			3		1314	1.7/1.0	70.0	0.0	-70.0	2.0	27903.6	42181.1	47 08.8884	122 46.4532			
18	**257**	1	1	3-Jun-99	1443	2.1/1.1	51.0	-0.2	-51.2	1.9	27902.6	42189.9	47 10.1353	122 44.1493	47 10.1358	122 44.1506	light VV
Drayton Passage			2		1457	2.2/1.1	50.5	-0.3	-50.8	2.4	27902.5	42189.8	47 10.1360	122 44.1487			
			3		1506	2.2/1.1	51.0	-0.3	-51.3	1.1	27902.6	42189.9	47 10.1361	122 44.1499			

Appendix C. Continued.

Stratum	Sample	Station	Deployment No.	Date	GPS Time	GPS PDOP/HDOP	Stern Transd. Depth m.	Predicted Tide (m.): Nearest Station	Predicted Mudline Depth, m. (MLLW)	Distance to Station (m)	LORAN-C Yankee	LORAN-C Zulu	DGPS (Trimble NT300D) NAD 1983 Decimal Minutes Latitude	DGPS Longitude	Station Target NAD 1983 Decimal Minutes Latitude	Station Target Longitude	Van Veen Grab Type
18	**258**	2--2	1		1547	2.0/1.2	44.5	-0.2	-44.7	0.7	27910.9	42191.4	47 11.4228	122 44.2204			
Drayton Passage			2	3-Jun-99	1557	2.0/1.2	44.5	-0.1	-44.6	1.4	27910.9	42191.4	47 11.4229	122 44.2209	47 11.4227	122 44.2201	heavy VV
			3		1605	3.7/2.2	44.5	0.0	-44.5	0.6	27910.9	42191.4	47 11.4228	122 44.2203			
18	**259**	3	1		0946	2.0/1.2	25.0	3.1	-21.9	0.7	27899.2	42189.7	47 09.7350	122 43.9769			
Drayton Passage			2	4-Jun-99	0957	2.0/1.3	25.0	3.0	-22.0	0.8	27899.3	42189.5	47 09.7353	122 43.9760	47 09.7354	122 43.9769	heavy VV
			3		1005	1.5/0.9	25.0	3.0	-22.0	1.9	27899.3	42189.6	47 09.7345	122 43.9764			
19	**260**	1--5	1		0936	2.1/1.2	127.0	2.5	-124.5	2.7	27876.1	42201.6	47 08.9011	122 39.5291			
East Anderson Island/No.			2	2-Jun-99	0952	1.9/1.1	127.0	2.4	-124.6	1.2	27876.1	42201.4	47 08.9025	122 39.5291	47 08.9022	122 39.5300	heavy VV
Cormorant Passage			3		1005	1.8/1.2	127.0	2.2	-124.8	1.1	27876.1	42201.5	47 08.9018	122 39.5307			
19	**261**	2--3	1		1449	2.6/1.5	131.0	-0.1	-131.1	1.2	27880.2	42200.2	47 09.1910	122 40.1393			
East Anderson Island/No.			2	1-Jun-99	1508	2.2/1.1	131.0	0.1	-130.9	1.8	27880.2	42200.3	47 09.1915	122 40.1380	47 09.1917	122 40.1395	heavy VV
Cormorant Passage			3		1521	2.2/1.1	133.0	0.2	-132.8	3.1	27880.3	42200.2	47 09.1909	122 40.1373			
19	**262**	3--2	1		1338	1.8/0.9	68.0	-0.4	-68.4	3.8	27875.0	42209.6	47 10.1510	122 37.2565			
East Anderson Island/No.			2	1-Jun-99	1351	1.8/0.9	68.0	-0.4	-68.4	0.9	27874.9	42209.7	47 10.1566	122 37.2555	47 10.1569	122 37.2560	heavy VV
Cormorant Passage			3		1401	1.8/0.9	68.0	-0.4	-68.4	2.0	27874.9	42209.6	47 10.1562	122 37.2549			
20	**263**	1	1		1021	1.5/0.9	75.0	1.2	-73.8	4.2	NA	NA	47 13.5995	122 39.5044			
Carr Inlet			2	31-May-99	1046	1.6/0.9	74.0	0.8	-73.2	0.9	27906.2	42208.0	47 13.5974	122 39.5063	47 13.5978	122 39.5067	heavy VV
			3		1102	1.8/1.0	74.0	0.6	-73.4	1.8	27906.1	42208.0	47 13.5972	122 39.5055			
			4		1119	1.8/1.0	75.0	0.4	-74.6	3.7	27906.1	42208.0	47 13.5980	122 39.5038			
20	**264**	2	1		1253	1.7/0.9	57.0	-0.4	-57.4	2.9	27955.9	42203.6	47 18.5594	122 43.6523			
Carr Inlet			2	31-May-99	1310	2.1/1.2	56.0	-0.4	-56.4	0.9	27956.0	42203.5	47 18.5588	122 43.6544	47 18.5593	122 43.6549	light VV
			3		1325	1.7/1.0	56.0	-0.4	-56.4	0.2	27955.9	42203.5	47 18.5593	122 43.6550			
			4		1337	1.8/0.9	56.0	-0.3	-56.3	1.1	27956.0	42203.6	47 18.5591	122 43.6541			
20	**265**	3	1		1455	2.6/1.5	105.0	0.3	-104.7	2.4	27918.2	42209.1	47 15.1449	122 39.9424			
Carr Inlet			2	31-May-99	1513	2.2/1.1	105.0	0.5	-104.5	1.3	27918.1	42209.1	47 15.1441	122 39.9424	47 15.1438	122 39.9434	light VV
			3		1531	2.2/1.1	106.0	0.8	-105.2	2.9	27918.1	42209.2	47 15.1441	122 39.9411			
21	**266**	1--2	1		1016	1.2/0.9	12.5	1.3	-11.2	1.7	27919.9	42214.3	47 16.1515	122 38.7456			
Hale Passage			2	1-Jun-99	1033	2.1/1.2	12.5	1.1	-11.4	1.0	27919.9	42214.5	47 16.1517	122 38.7442	47 16.1512	122 38.7442	heavy VV
			3		1100	1.8/1.0	12.0	0.7	-11.3	1.5	27919.9	42214.3	47 16.1505	122 38.7446			
21	**267**	2	1		0914	2.4/1.2	26.0	2.1	-23.9	1.0	NA	NA	47 16.1957	122 36.0655			
Hale Passage			2	1-Jun-99	0924	2.4/1.2	26.0	2.0	-24.0	1.7	NA	NA	47 16.1955	122 36.0645	47 16.1956	122 36.0662	heavy VV
			3		0940	2.1/1.2	26.0	1.8	-24.2	0.7	27909.5	42222.1	47 16.1955	122 36.0659			
			4		0947	2.0/1.1	26.0	1.7	-24.3	0.6	27909.5	42222.3	47 16.1957	122 36.0658			

Appendix C. Continued.

Stratum / Location	Sample	Station	Deploy-ment No.	Date	GPS Time	GPS PDOP/HDOP	Stern Transd. Depth m.	Predicted Tide (m.): Nearest Station	Predicted Mudline Depth, m. (MLLW)	Distance to Station (m)	LORAN-C Yankee	LORAN-C Zulu	DGPS (Trimble NT300D) NAD 1983 Decimal Minutes Latitude	DGPS Longitude	Station Target NAD 1983 Decimal Minutes Latitude	Station Target Longitude	Van Veen Grab Type
21	**268**	3	1	31-May-99	1641	1.9/1.0	51.0	2.1	-48.9	4.5	27902.5	42221.1	47 15.2758	122 35.8849	47 15.2780	122 35.8865	heavy VV
Hale Passage			2		1652	1.8/1.0	51.0	2.2	-48.8	1.2	27902.6	42221.2	47 15.2783	122 35.8871			
			3		1703	1.9/1.0	52.0	2.3	-49.7	4.4	27902.6	42221.2	47 15.2796	122 35.8837			
			4		1714	2.3/1.2	52.0	2.5	-49.5	6.6	27902.6	42221.1	47 15.2814	122 35.8841			
			5		1732	2.3/1.2	53.0	2.7	-50.3	3.6	27902.6	42221.2	47 15.2772	122 35.8837			
			6		1755	2.0/1.1	53.0	3.0	-50.0	10.5	27902.6	42221.2	47 15.2802	122 35.8786			
22	**269**	1--2	1	22-Jun-99	1542	2.3/1.2	7.1	2.3	-4.8	0.3	27933.2	42231.4	47 20.2736	122 35.0692	47 20.2735	122 35.0692	heavy VV
Gig Harbor			2		1610	2.3/1.2	7.0	2.2	-4.8	1.3	27933.2	42231.5	47 20.2739	122 35.0683			
			3		1618	2.3/1.2	7.0	2.2	-4.8	0.5	27933.2	42231.4	47 20.2733	122 35.0690			
22	**270**	2	1	22-Jun-99	1641	1.9/1.1	7.0	2.1	-4.9	1.2	27931.0	42232.3	47 20.1287	122 34.7566	47 20.1284	122 34.7574	heavy VV
Gig Harbor			2		1651	2.0/1.3	7.0	2.0	-5.0	0.6	27931.0	42232.2	47 20.1285	122 34.7579			
			3		1658	2.0/1.3	7.0	1.9	-5.1	0.2	27931.0	42232.2	47 20.1283	122 34.7573			
22	**271**	3	1	22-Jun-99	0856	2.1/1.2	9.5	0.8	-8.7	1.4	27931.9	42231.5	47 20.1245	122 34.9825	47 20.1244	122 34.9836	lightest VV
Gig Harbor			2		0907	2.0/1.1	9.5	0.8	-8.7	0.8	27931.8	42231.4	47 20.1241	122 34.9832			
			3		0918	1.5/0.9	9.5	0.9	-8.6	0.9	27931.8	42231.5	47 20.1243	122 34.9829			
23	**272**	1--2	1	22-Jun-99	1220	1.8/0.9	46.0	2.2	-43.8	0.9	27972.6	42259.9	47 28.4297	122 30.1300	47 28.4295	122 30.1306	heaviest VV
Colvos Passage			2		1336	1.8/0.9	46.0	2.3	-43.7	0.4	27972.6	42260.0	47 28.4297	122 30.1307			
			3		1346	2.3/1.1	45.5	2.3	-43.2	2.6	27972.6	42259.9	47 28.4281	122 30.1301			
23	**273**	2	1	22-Jun-99	1113	2.3/1.4	102.0	1.8	-100.2	0.7	27985.2	42266.5	47 30.6408	122 29.1538	47 30.6412	122 29.1539	heaviest VV
Colvos Passage			2		1135	2.1/1.2	102.0	2.0	-100.0	2.5	27985.2	42266.5	47 30.6405	122 29.1558			
			3		1145	1.8/1.1	102.2	2.0	-100.2	1.2	27985.2	42266.5	47 30.6413	122 29.1542			
			4		1157	1.7/1.0	102.2	2.1	-100.1	0.9	27985.2	42266.4	47 30.6414	122 29.1545			
23	**274**	3	1	22-Jun-99	1343	2.2/1.1	97.5	2.4	-95.1	1.6	27973.0	42259.0	47 28.3282	122 30.4164	47 28.3289	122 30.4155	heaviest VV
Colvos Passage			2		1356	2.2/1.1	97.5	2.4	-95.1	1.4	27972.9	42258.8	47 28.3284	122 30.4147			
			3		1406	2.2/1.1	98.0	2.4	-95.6	0.8	27972.9	42258.9	47 28.3288	122 30.4162			
24	**275**	1	1	21-Jun-99	1122	1.17/0.9	16.0	2.3	-13.7	0.9	27916.1	42252.7	47 21.4631	122 28.6699	47 21.4626	122 28.6702	heavy VV
Quartermaster Harbor			2		1131	1.7/0.9	16.0	2.3	-13.7	1.8	27916.0	42252.8	47 21.4632	122 28.6715			
			3		1140	1.7/0.9	16.0	2.3	-13.7	1.1	27916.0	42252.7	47 21.4629	122 28.6709			
			4		1148	2.1/1.1	16.0	2.3	-13.7	0.5	27916.0	42252.7	47 21.4628	122 28.6699			
24	**276**	2	1	21-Jun-99	0957	1.8/1.0	14.5	1.8	-12.7	0.6	27924.4	42256.8	47 23.0025	122 28.1152	47 23.0028	122 28.1154	heavy VV
Quartermaster Harbor			2		1008	1.7/1.0	14.6	1.9	-12.7	0.3	27924.3	42256.7	47 23.0026	122 28.1154			
			3		1017	1.7/1.0	14.7	2.0	-12.7	0.9	27924.3	42256.7	47 23.0031	122 28.1150			
24	**277**	3	1	21-Jun-99	1039	2.2/1.2	21.9	2.1	-19.8	0.6	27922.9	42253.5	47 22.3635	122 28.9075	47 22.3633	122 28.9080	heavy VV
Quartermaster Harbor			2		1050	2.2/1.1	22.0	2.1	-19.9	1.3	27922.9	42253.4	47 22.3634	122 28.9069			
			3		1059	2.2/1.1	22.0	2.2	-19.8	0.8	27922.9	42253.5	47 22.3636	122 28.9075			

Appendix C. Continued.

Stratum	Sample	Station	Deploy-ment No.	Date	GPS Time	GPS PDOP/HDOP	Stern Transd. Depth m.	Predicted Tide (m.): Nearest Station	Predicted Mudline Depth, m. (MLLW)	Distance to Station (m)	LORAN-C Yankee	LORAN-C Zulu	DGPS (Trimble NT300D) NAD 1983 Decimal Minutes Latitude	DGPS (Trimble NT300D) NAD 1983 Decimal Minutes Longitude	Station Target NAD 1983 Decimal Minutes Latitude	Station Target NAD 1983 Decimal Minutes Longitude	Van Veen Grab Type
25	**278**	1	1	21-Jun-99	1437	2.0/1.2	177.0	2.0	-175.0	1.8	27896.1	42254.8	47 19.6152	122 26.9518	47 19.6160	122 26.9519	heaviest VV
East Passage			2		1501	4.0/2.4	177.5	1.9	-175.6	3.9	27896.0	42254.8	47 19.6155	122 26.9487			
			3		1520	1.9/1.0	177.5	1.8	-175.7	2.1	27895.9	42254.6	47 19.6148	122 26.9508			
25	**279**	2--2	1	17-Jun-99	1025	1.7/1.0	170.0	1.8	-168.2	1.4	27892.0	42262.3	47 20.3606	122 24.7112	47 20.3608	122 24.7121	heavy VV
East Passage			2		1043	2.3/1.3	170.0	1.6	-168.4	1.4	27892.0	42262.3	47 20.3601	122 24.7116			
			3		1105	2.2/1.1	170.0	1.3	-168.7	1.3	27892.0	42262.4	47 20.3604	122 24.7126			
25	**280**	3	1	21-Jun-99	1217	2.4/1.2	54.0	2.4	-51.6	1.4	27902.2	42255.1	47 20.3781	122 27.2308	47 20.3785	122 27.2318	heaviest VV
East Passage			2		1336	2.1/1.1	53.5	2.3	-51.2	2.0	27902.2	42255.1	47 20.3781	122 27.2303			
			3		1346	2.2/1.1	54.0	2.3	-51.7	2.9	27902.2	42255.1	47 20.3790	122 27.2296			
			4		1359	2.2/1.1	54.0	2.2	-51.8	1.1	27902.2	42255.1	47 20.3779	122 27.2316			
26	**281**	1	1	17-Jun-99	1143	1.7/0.9	140.5	0.8	-139.7	1.5	27880.1	42252.5	47 17.5372	122 26.5170	47 17.5372	122 26.5156	heavy VV
Outer Commencement Bay			2		1158	1.7/0.9	140.0	0.6	-139.4	1.4	27880.1	42252.5	47 17.5379	122 26.5151			
			3		1218	1.7/1.0	140.0	0.4	-139.6	0.2	27880.0	42252.4	47 17.5371	122 26.5155			
26	**282**	2	1	16-Jun-99	1112	2.2/1.1	148.5	0.4	-148.1	1.3	27882.5	42247.7	47 17.0998	122 27.8920	47 17.1003	122 27.8927	heaviest VV
Outer Commencement Bay			2		1128	2.1/1.1	148.5	0.2	-148.3	1.6	27882.6	42247.8	47 17.1006	122 27.8914			
			3		1151	1.7/0.9	148.0	-0.1	-148.1	0.4	27882.6	42247.8	47 17.1002	122 27.8925			
26	**283**	3	1	16-Jun-99	1359	2.2/1.1	165.5	-0.8	-166.3	1.1	27889.0	42251.2	47 18.3066	122 27.4132	47 18.3070	122 27.4126	heavy VV
Outer Commencement Bay			2		1421	2.2/1.1	166.0	-0.7	-166.7	0.9	27889.0	42251.2	47 18.3068	122 27.4120			
			3		1437	2.2/1.1	166.0	-0.6	-166.6	1.3	27889.0	42251.2	47 18.3071	122 27.4116			
26	**284**	4	1	16-Jun-99	1259	1.8/0.9	164.0	-0.8	-164.8	0.6	27896.1	42246.8	47 18.4628	122 28.9288	47 18.4631	122 28.9287	lightest VV
Outer Commencement Bay			2		1316	2.6/1.2	164.0	-0.8	-164.8	1.1	27896.2	42246.9	47 18.4634	122 28.9279			
			3		1331	2.4/1.3	164.0	-0.9	-164.9	0.9	27896.1	42246.9	47 18.4632	122 28.9282			
27	**285**	1	1	15-Jun-99	1426	2.2/1.1	17.6	-0.4	-18.0	3.6	27881.5	42246.3	47 16.7421	122 28.1964	47 16.7425	122 28.1936	heaviest VV
S.E. Commencement Bay			2		1437	2.2/1.1	17.5	-0.3	-17.8	2.7	27881.4	42246.4	47 16.7410	122 28.1938			
(shoreline)			3		1446	2.1/1.1	18.0	-0.1	-18.1	2.1	27881.4	42246.4	47 16.7421	122 28.1921			
27	**286**	2	1	16-Jun-99	0955	1.8/1.0	106.0	1.6	-104.4	0.5	27884.3	42246.4	47 17.0924	122 28.3241	47 17.0923	122 28.3244	heaviest VV
S.E. Commencement Bay			2		1011	1.8/1.0	105.5	1.4	-104.1	2.2	27884.3	42246.5	47 17.0935	122 28.3250			
(shoreline)			3		1024	1.8/1.0	105.3	1.2	-104.1	0.8	27884.3	42246.5	47 17.0926	122 28.3239			
27	**287**	3	1	16-Jun-99	0909	1.4/0.9	34.0	2.2	-31.8	1.4	27872.0	42249.5	47 16.1731	122 26.8219	47 16.1733	122 26.8208	heaviest VV
S.E. Commencement Bay			2		0921	2.1/1.2	33.5	2.1	-31.4	1.5	27872.0	42249.4	47 16.1725	122 26.8207			
(shoreline)			3		0930	2.1/1.2	33.5	2.0	-31.5	0.7	27872.0	42249.5	47 16.1730	122 26.8213			
28	**288**	1	1	15-Jun-99	1036	1.9/1.1	96.0	0.2	-95.8	1.3	27874.1	42251.4	47 16.7602	122 26.3988	47 16.7600	122 26.3977	heavy VV
S.E. Commencement Bay			2		1047	2.1/1.2	95.5	-0.1	-95.6	1.5	27874.2	42251.5	47 16.7603	122 26.3990			
			3		1102	2.2/1.2	95.5	-0.3	-95.8	1.8	27874.1	42251.5	47 16.7599	122 26.3962			

Appendix C. Continued.

Stratum	Sample	Station	Location	Deployment No.	Date	GPS Time	GPS PDOP/HDOP	Stern Transd. Depth m.	Predicted Tide (m.): Nearest Station	Predicted Mudline Depth, m. (MLLW)	Distance to Station (m)	LORAN-C Yankee	LORAN-C Zulu	DGPS (Trimble NT300D) NAD 1983 Decimal Minutes Latitude	DGPS (Trimble NT300D) NAD 1983 Decimal Minutes Longitude	Station Target NAD 1983 Decimal Minutes Latitude	Station Target NAD 1983 Decimal Minutes Longitude	Van Veen Grab Type
28	**289**	2	S.E. Commencement Bay	1	15-Jun-99	1135	2.8/1.5	118.0	-0.6	-118.6	1.6	27876.1	42249.4	47 16.6473	122 27.0578	47 16.6480	122 27.0584	heaviest VV
				2		1156	1.7/0.9	119.0	-0.8	-119.8	1.3	27876.0	42249.4	47 16.6474	122 27.0590			
				3		1212	2.1/1.1	119.0	-0.9	-119.9	1.9	27876.1	42249.4	47 16.6471	122 27.0580			
				4		1228	1.7/1.0	119.0	-1.0	-120.0	1.1	27876.1	42249.4	47 16.6474	122 27.0586			
28	**290**	3	S.E. Commencement Bay	1	15-Jun-99	1333	2.7/1.4	116.0	-0.9	-116.9	0.9	27876.5	42250.3	47 16.8396	122 26.8449	47 16.8400	122 26.8446	heaviest VV
				2		1347	2.5/1.5	115.0	-0.8	-115.8	0.4	27876.5	42250.2	47 16.8400	122 26.8450			
				3		1400	2.1/1.1	115.5	-0.7	-116.2	0.4	27876.5	42250.3	47 16.8398	122 26.8449			
29	**291**	1	N.E. Commencement Bay	1	17-Jun-99	1320	2.7/1.3	89.0	-0.3	-89.3	0.3	27875.3	42254.0	47 17.2721	122 25.8342	47 17.2721	122 25.8344	heavy VV
				2		1332	2.7/1.4	89.5	-0.4	-89.9	1.0	27875.3	42254.0	47 17.2719	122 25.8337			
				3		1343	2.5/1.5	89.5	-0.5	-90.0	1.1	27875.3	42254.0	47 17.2722	122 25.8353			
29	**292**	2	N.E. Commencement Bay	1	17-Jun-99	1408	2.2/1..1	21.3	-0.5	-21.8	0.5	27874.4	42256.1	47 17.5281	122 25.1929	47 17.5280	122 25.1932	heavy VV
				2		1420	2.1/1.1	21.5	-0.6	-22.1	0.8	27874.4	42256.2	47 17.5283	122 25.1936			
				3		1428	2.1/1.1	21.5	-0.6	-22.1	1.2	27874.4	42256.2	47 17.5286	122 25.1926			
29	**293**	3	N.E. Commencement Bay	1	17-Jun-99	1457	2.0/1.2	9.3	-0.5	-9.8	2.0	27878.6	42255.1	47 17.8171	122 25.7570	47 17.8160	122 25.7567	heavy VV
				2		1510	2.3/1.4	9.5	-0.4	-9.9	1.8	27878.6	42255.1	47 17.8163	122 25.7581			
				3		1520	2.3/1.4	9.5	-0.4	-9.9	1.4	27878.6	42255.0	47 17.8168	122 25.7569			
30	**294**	1	Thea Foss Waterway	1	14-Jun-99	1520	4.0/2.4	2.7	1.2	-1.5	0.5	27859.8	42249.9	47 14.9500	122 25.8996	47 14.9497	122 25.8998	heavy VV
				2		1538	1.8/1.0	2.9	1.5	-1.4	0.3	27859.8	42250.0	47 14.9499	122 25.8998			
				3		1546	1.9/1.0	2.9	1.6	-1.3	0.9	27859.8	42250.0	47 14.9493	122 25.8994			
				4		1553	1.8/1.0	3.0	1.8	-1.2	1.2	27859.8	42249.9	47 14.9496	122 25.9007			
30	**295**	2	Thea Foss Waterway	1	14-Jun-99	0958	1.8/1.0	9.5	0.0	-9.5	0.3	27864.1	42250.5	47 15.4830	122 26.0666	47 15.4829	122 26.0665	light VV
				2		1016	1.8/1.0	9.3	-0.2	-9.5	0.6	27864.1	42250.5	47 15.4828	122 26.0661			
				3		1028	1.8/1.0	9.2	-0.4	-9.6	1.1	27864.2	42250.5	47 15.4835	122 26.0667			
30	**296**	3	Thea Foss Waterway	1	14-Jun-99	1103	1.7/1.0	9.1	-0.8	-9.9	0.8	27864.6	42250.4	47 15.5312	122 26.1064	47 15.5314	122 26.1058	light VV
				2		1114	2.2/1.2	9.1	-0.9	-10.0	1.0	27864.6	42250.4	47 15.5315	122 26.1066			
				3		1124	2.2/1.1	9.0	-0.9	-9.9	0.7	27864.6	42250.5	47 15.5317	122 26.1055			
				4		1135	2.1/1.1	8.9	-1.0	-9.9	0.9	27864.6	42250.5	47 15.5317	122 26.1053			
31	**297**	1	Middle Waterway	1	14-Jun-99	1307	1.7/0.9	9.6	-0.7	-10.3	0.4	27866.9	42251.3	47 15.9169	122 26.0001	47 15.9167	122 26.0000	heavy VV
				2		1326	2.6/1.3	9.8	-0.6	-10.4	1.4	27866.8	42251.4	47 15.9172	122 25.9993			
				3		1335	2.7/1.3	10.1	-0.5	-10.6	0.9	27866.9	42251.3	47 15.9170	122 26.0006			
				4		1342	2.7/1.4	10.0	-0.4	-10.4	0.6	27866.9	42251.4	47 15.9170	122 26.0000			
31	**298**	2	Middle Waterway	1	14-Jun-99	1410	2.2/1.1	5.7	0.0	-5.7	0.7	27866.6	42251.2	47 15.8750	122 26.0077	47 15.8750	122 26.0083	heavy VV
				2		1433	1.9/1.0	5.5	0.4	-5.1	7.9	27866.6	42251.3	47 15.8708	122 26.0074			
				3		1440	2..2/1.1	6.0	0.5	-5.5	8.1	27866.6	42251.3	47 15.8707	122 26.0070			
				4		1448	2.1/1.1	6.0	0.6	-5.4	7.4	27866.5	42251.3	47 15.8711	122 26.0072			

Appendix C. Concluded.

Stratum	Sample	Station	Deployment No.	Date	GPS Time	GPS PDOP/HDOP	Stern Transd. Depth m.	Predicted Tide (m.): Nearest Station	Predicted Mudline Depth, m. (MLLW)	Distance to Station (m)	LORAN-C Yankee	LORAN-C Zulu	DGPS (Trimble NT300D) NAD 1983 Decimal Minutes Latitude	DGPS Longitude	Station Target NAD 1983 Decimal Minutes Latitude	Station Target Longitude	Van Veen Grab Type
31	**299**	3	1	15-Jun-99	0917	1.5/0.9	11.0	1.5	-9.5	0.6	27866.3	42251.3	47 15.8579	122 25.9665	47 15.8583	122 25.9667	heavy VV
Middle Waterway			2		0926	2.1/1.2	10.8	1.3	-9.5	1.2	27866.3	42251.3	47 15.8587	122 25.9674			
			3		0950	1.8/1.0	10.5	0.9	-9.6	1.9	27866.4	42251.3	47 15.8573	122 25.9663			
			4		0957	1.8/1.0	10.5	0.8	-9.7	2.2	27866.3	42251.3	47 15.8581	122 25.9650			
			5		1006	1.8/1.0	10.3	0.6	-9.7	2.0	27866.3	42251.3	47 15.8592	122 25.9657			
32	**300**	1	1	17-Jun-99	0939	1.8/1.0	17.5	2.7	-14.8	0.7	27854.4	42258.8	47 15.7300	122 23.2828	47 15.7304	122 23.2828	heavy VV
Blair Waterway			2		0951	1.8/1.0	17.7	2.6	-15.1	2.1	27854.3	42258.7	47 15.7312	122 23.2816			
			3		1001	1.8/1.0	17.5	2.5	-15.0	1.0	27854.4	42258.8	47 15.7304	122 23.2820			
32	**301**	2	1	17-Jun-99	1029	1.7/1.0	16.7	2.3	-14.4	0.4	27854.0	42258.8	47 15.7177	122 23.2371	47 15.7179	122 23.2372	heavy VV
Blair Waterway			2		1038	2.3/1.3	16.6	2.2	-14.4	0.3	27854.0	42259.0	47 15.7180	122 23.2369			
			3		1052	2.2/1.1	16.5	2.2	-14.3	1.1	27854.0	42258.9	47 15.7182	122 23.2364			
32	**302**	3	1	17-Jun-99	1129	2.3/1.4	16.1	1.8	-14.3	0.7	27851.0	42259.5	47 15.5052	122 22.8720	47 15.5052	122 22.8726	heavy VV
Blair Waterway			2		1139	1.7/0.9	16.0	1.6	-14.4	1.3	27851.0	42259.5	47 15.5059	122 22.8727			
			3		1147	1.7/0.9	15.9	1.6	-14.3	0.4	27851.0	42259.5	47 15.5052	122 22.8729			
33	**303**	1	1	17-Jun-99	1259	2.3/1.1	9.7	0.7	-9.0	1.5	27859.2	42260.4	47 16.5437	122 23.1614	47 16.5437	122 23.1614	heavy VV
Hylebos Waterway			2		1312	2.6/1.3	9.5	0.6	-8.9	0.2	27859.3	42260.4	47 16.5437	122 23.1614			
			3		1322	2.6/1.3	9.5	0.5	-9.0	0.5	27859.3	42260.3	47 16.5437	122 23.1614			
33	**304**	2	1	17-Jun-99	1407	2.2/1.1	10.2	0.0	-10.2	1.2	27863.5	42258.5	47 16.7191	122 23.9049	47 16.7189	122 23.9059	heavy VV
Hylebos Waterway			2		1418	2.2/1.1	10.1	0.0	-10.1	1.2	27863.5	42258.6	47 16.7193	122 23.9066			
			3		1431	2.1/1.1	10.1	-0.1	-10.2	1.2	27863.5	42258.6	47 16.7183	122 23.9054			
			4		1444	2.0/1.2	10.0	-0.1	-10.1	1.1	27863.5	42258.5	47 16.7189	122 23.9050			
33	**305**	3--3	1	17-Jun-99	1515	4.1/2.4	6.0	-0.2	-6.2	0.9	27865.0	42258.2	47 16.8191	122 24.0889	47 16.8190	122 24.0883	heavy VV
Hylebos Waterway			2		1527	1.9/1.0	6.0	-0.2	-6.2	1.0	27865.0	42258.1	47 16.8192	122 24.0888			
			3		1535	2.1/1.1	6.0	-0.2	-6.2	1.3	27864.9	42258.1	47 16.8198	122 24.0886			

Appendix D

NOAA Sediment Guidelines and Washington State Criteria.

Appendix D. NOAA sediment quality guidelines and Washington State sediment quality criteria.

	NOAA Guidelines			Washington State Criteria		
Chemical	ERL[1]	ERM[1]	Unit[1]	SOS[2]	CSL	Unit[2]
Trace metals						
Arsenic	8.2	70	PPM Dry Weight	57	93	PPM Dry Weight
Cadmium	1.2	9.6	PPM Dry Weight	5.1	6.7	PPM Dry Weight
Chromium	81	370	PPM Dry Weight	260	270	PPM Dry Weight
Copper	34	270	PPM Dry Weight	390	390	PPM Dry Weight
Lead	46.7	218	PPM Dry Weight	450	530	PPM Dry Weight
Mercury	0.15	0.71	PPM Dry Weight	0.41	0.59	PPM Dry Weight
Nickel	20.9	51.6	PPM Dry Weight	NA	NA	PPM Dry Weight
Silver	1	3.7	PPM Dry Weight	6.1	6.1	PPM Dry Weight
Zinc	150	410	PPM Dry Weight	410	960	PPM Dry Weight
Organic Chemicals						
LPAH						
2-Methylnaphthalene	70	670	PPB dry weight	38	64	PPM Organic Carbon
Acenaphthene	16	500	PPB dry weight	16	57	PPM Organic Carbon
Acenaphthylene	44	640	PPB dry weight	66	66	PPM Organic Carbon
Anthracene	85.3	1100	PPB dry weight	220	120	PPM Organic Carbon
Fluorene	19	540	PPB dry weight	23	79	PPM Organic Carbon
Naphthalene	160	2100	PPB dry weight	99	170	PPM Organic Carbon
Phenanthrene	240	1500	PPB dry weight	100	480	PPM Organic Carbon
Sum of LPAHs:						
Sum of 6 LPAH (Ch. 173-204 WAC)	NA	NA		370	780	PPM Organic Carbon
Sum of 7 LPAH (Long et al., 1995)	552	3160	PPB dry weight	NA	NA	
HPAH						
Benzo(a)anthracene	261	1600	PPB dry weight	110	270	PPM Organic Carbon
Benzo(a)pyrene	430	1600	PPB dry weight	99	210	PPM Organic Carbon
Benzo(g,h,I)perylene	NA	NA		31	78	PPM Organic Carbon

Appendix D. Continued.

	NOAA Guidelines			Washington State Criteria		
Chemical	ERL[1]	ERM[1]	Unit[1]	SOS[2]	CSL	Unit[2]
Chrysene	384	2800	PPB dry weight	110	460	PPM Organic Carbon
Dibenzo(a,h)anthracene	63.4	260	PPB dry weight	12	33	PPM Organic Carbon
Fluoranthene	600	5100	PPB dry weight	160	120	PPM Organic Carbon
Indeno(1,2,3-c,d)pyrene	NA	NA		34	88	PPM Organic Carbon
Pyrene	665	2600	PPB dry weight	1000	140	PPM Organic Carbon
Total Benzofluoranthenes	NA	NA		230	450	PPM Organic Carbon
Sum of HPAHs:						
Sum of 9 HPAH (Ch. 173-204 WAC)	NA	NA		960	530	PPM Organic Carbon
Sum of 6 HPAH (Long et al., 1995)	1700	9600	PPB dry weight	NA	NA	
Sum of 13 PAHs	4022	44792	PPB dry weight	NA	NA	
Phenols						
2,4-Dimethylphenol	NA	NA		29	29	PPB Dry Weight
2-Methylphenol	NA	NA		63	63	PPB Dry Weight
4-Methylphenol	NA	NA		670	670	PPB Dry Weight
Pentachlorophenol	NA	NA		360	690	PPB Dry Weight
Phenol	NA	NA		420	120	PPB Dry Weight
Phthalate Esters						
Bis (2-Ethylhexyl) Phthalate	NA	NA		47	78	PPM Organic Carbon
Butylbenzylphthalate	NA	NA		4.9	64	PPM Organic Carbon
Diethylphthalate	NA	NA		61	110	PPM Organic Carbon
Dimethylphthalate	NA	NA		53	53	PPM Organic Carbon
Di-N-Butyl Phthalate	NA	NA		220	170	PPM Organic Carbon
Di-N-Octyl Phthalate	NA	NA		58	450	PPM Organic Carbon
Chlorinated Pesticide and PCBs						
4,4'-DDE	2.2	27	PPB dry weight	NA	NA	
Total DDT	1.58	46.1	PPB dry weight	NA	NA	
Total PCB:						
Total Aroclors (Ch. 173-204 WAC)	NA	NA		12	65	PPM Organic Carbon
Total congeners (Long et al., 1995):	22.7	180	PPB dry weight	NA	NA	

Appendix D. Concluded.

Chemical	NOAA Guidelines ERL[1]	ERM[1]	Unit[1]	Washington State Criteria SOS[2]	CSL	Unit[2]
Miscellaneous Chemicals						
1,2-Dichlorobenzene	NA	NA		2.3	2.3	PPM Organic Carbon
1,2,4-Trichlorobenzene	NA	NA		0.81	1.8	PPM Organic Carbon
1,4-Dichlorobenzene	NA	NA		3.1	9	PPM Organic Carbon
Benzoic Acid	NA	NA		650	650	PPB Dry Weight
Benzyl Alcohol	NA	NA		57	73	PPB Dry Weight
Dibenzofuran	NA	NA		15	58	PPM Organic Carbon
Hexachlorobenzene	NA	NA		0.38	2.3	PPM Organic Carbon
Hexachlorobutadiene	NA	NA		3.9	6.2	PPM Organic Carbon
N-Nitrosodiphenylamine	NA	NA		11	11	PPM Organic Carbon

[1] Long, Edward R., Donald D. Macdonald, Sherri L. Smith and Fred D. Calder. 1995. Incidence of adverse biological effect with ranges of chemical concentrations in marine and estuarine sediments. Environmental Management 19(1): 81-97.

[2] Sediment Management Standard Chapter 173-204, Amended December 1995

Appendix E

Infaunal taxa removed from the 1999 southern Puget Sound list of benthic infauna.

Appendix E. Species eliminated from the 1999 southern Puget Sound list of benthic infauna.

Elimination Criteria	Phylum	Class	Family	Taxon	Authorship
Incidental[1]				Cyclopoida	
		Insecta	Tipulinae	Ctenophora	Meigen, 1803
	Ctenophora			Ctenophora	
		Cirripedia	Balanidae	Balanus sp	
			Hyperiidae	Hyperiidae	
Meiofauna[2]		Copepoda		Calanoida	Mauchline, 1988
				Calanus pacificus	Brodsky, 1948
				Harpacticoida	
Presence/ Absence[3]	Porifera	Demospongiae		Demospongiae	
		Hydrozoa	Aglaopheniidae	Aglaophenia diegensis	Torrey, 1904
			Campanulariidae	Clytia sp	
				Obelia dichotoma	(Linnaeus, 1758)
			Corymorphidae	Euphysa ruthae	Norenburg and Morse, 1983
			Hydromedusae	Hydromedusa	
			Lafoeidae	Lagenicella neosocialis	
			Pandeidae	Pandeidae	
			Plumulariidae	Plumularia setacea	(Linnaeus, 1758)
			Sertulariidae	Abietinaria sp	
				Hydrallmania distans	Nutting, 1899
				Selaginopsis triserialis	Mereschkowsky, 1878

Appendix E. Concluded.

Elimination Criteria	Phylum	Class	Family	Taxon	Authorship
				Sertularella sp	
			Tubulariidae	Ectopleura marina	
	Bryozoa	Gymnolaemata	Alcyonidiidae	Alcyonidium sp	
			Hippothoidae	Celleporella hyalina	(Linnaeus, 1767)
			Vesiculariidae	Bowerbankia gracilis	Leidy, 1855
	Entoprocta		Barentsiidae	Barentsia benedeni	(Foettinger, 1887)
				Barentsia gracilis	
			Pedicellinidae	Myosoma spinosa	

Incidental[1]: organisms caught which are not soft sediment infaunal invertebrates -e.g., hard substrate dwellers, larval species, etc.
Meiofauna[2]: organisms which are smaller than the infaunal fraction but accidentally caught by the 1 mm screen.
Presence/Absence[3]: organisms, such as colonial species, for which a count of individuals cannot be made.

Appendix F

Field notes for the 1999 southern Puget Sound sampling stations.

Appendix F. Field notes for the 1999 southern Puget Sound sampling stations.

Stratum, Sample, Station, Location	Station Description	Salinity (ppt)	Temperature (°C)	Sediment Type	Sediment Color	Sediment Odor and intensity	Penetration depth (cm)	RPD (cm)
1, 206, 1, Port Ludlow	suburban	30	11	Silt-clay, wood	olive gray	none	17	1-2
1, 207, 2, Port Ludlow	suburban, residential	30	12	very silty sand	brown	none	11	none
1, 208, 3, Port Ludlow	residential, marina	30	14	sand	light brown surface over gray	none	9	none
2, 209, 1, Hood Canal (north)	residential	30	11	silty sand	gray	none	10	none
2, 210, 2, Hood Canal (north)	residential	30	11	sand	gray	none	10	none
2, 211, 3, Hood Canal (north)	suburban	31	11.5	sand, shell	gray	none	6	none
3, 212, 1, Port Gamble Bay	rural, net pens	30	12	very silty sand	gray brown	none	9	none
3, 213, 2, Port Gamble Bay	rural, suburban	30	13.5	very silty sand	gray brown	none	7	Not Recorded
3, 214, 3, Port Gamble Bay	rural, suburban	30	12	Silt-clay, wood	olive over gray	slight sulfur	17	1-2
4, 215, 1, Quilcene Bay	rural	25	11	silt-clay	gray	none	15	Not Recorded
4, 216, 2, Quilcene Bay	rural	27	12	silt-clay	gray	none	15	Not Recorded
4, 217, 3, Quilcene Bay	rural	30	11	sand, silt-clay	gray brown	none	11	Not Recorded
5, 218, 1, Dabob Bay	rural	29	11	silt-clay	gray brown	none	15	Not Recorded
5, 219, 2, Dabob Bay	rural	25	12	silt-clay	gray	none	17	none
5, 220, 3, Dabob Bay	rural	27	12	silt-clay	gray brown	none	17	none
6, 221, 1, Hood Canal (central)	rural	25	12	silt-clay	brown	none	17	none
6, 222, 2, Hood Canal (central)	rural	30	11.5	coarse sand, silt-clay	gray brown	none	17	none
6, 223, 3, Hood Canal (central)	rural	27	12	silt-clay	gray	none	17	none
7, 224, 1, Hood Canal (south)	rural	24	11.5	silt-clay	gray brown	strong sulfur	17	none
7, 225, 2, Hood Canal (south)	suburban	25	11.5	silt-clay	gray brown	strong sulfur	17	none
7, 226, 3, Hood Canal (south)	rural	25	11	silt-clay	brown	none	17	none
8, 227, 1, Port of Shelton	urban	27	15	silty sand	gray	none	17	none

Appendix F. Continued.

Stratum, Sample, Station, Location	Station Description	Salinity (ppt)	Temperature (°C)	Sediment Type	Sediment Color	Sediment Odor and intensity	Penetration depth (cm)	RPD (cm)
8, 228, 2, Port of Shelton	urban	25	15	sand, silt-clay, wood	gray	none	17	none
8, 229, 3, Port of Shelton	urban	25	14.5	sand silt-clay, wood	olive gray	none	14.5	none
9, 230, 1, Oakland Bay	urban	27	13	Silt-clay, wood	gray brown	strong sulfur	14	Not Recorded
9, 231, 2, Oakland Bay	rural/suburban	27	14.5	silt-clay	gray	slight sulfur	17	none
9, 232, 3, Oakland Bay	suburban	27	14	sand, silt-clay	gray	moderate sulfur	17	Not Recorded
10, 233, 1, Totten Inlet	rural	30	14	sand , silt-clay, wood, shell, plant fragments	gray over black	none	17	2.5
10, 234, 2, Totten Inlet	rural	28	13.5	sand, silt-clay	gray over black	none	17	thin line
10, 235, 3, Totten Inlet	rural	30	13	sand, silt-clay, wood, shell, plant fragments	gray over black	none	17	3
11, 238, 1, Budd Inlet	rural	30	12	sand, silt-clay, shell	olive over black	strong sulfur	17	1
11, 239, 2, Eld Inlet	rural	30	12	silt-clay, plant fragments	olive over black	strong sulfur	17	1
11, 240, 3, Eld Inlet	rural	30	12	sand, silty-clay	black	strong sulfur	17	all black
12, 236, 1, Budd Inlet	rural	30	12	sand, silt-clay	olive over black	sulfur	17	fine line
12, 237, 2, Budd Inlet	rural	30	12	silt-clay	brown over black	none	16	>4
12, 241, 3, Eld Inlet	rural	30	11.75	silt-clay	brown over black	none	16	>4
13, 242, 1, Port of Olympia	urban	30	12	silt-clay	black	strong sulfur	17	0

Appendix F. Continued.

Stratum, Sample, Station, Location	Station Description	Salinity (ppt)	Temperature (°C)	Sediment Type	Sediment Color	Sediment Odor and intensity	Penetration depth (cm)	RPD (cm)
13, 243, 2, Port of Olympia	urban	30	12	silt-clay	black	strong sulfur	17	0
13, 244, 3, Port of Olympia	urban	31	13	silt-clay, wood	brown over black	strong sulfur	16	.5
14, 245, 1, Pickering Passage/Squaxin Island	rural	30	13	silty sand	gray brown	none	7	none
14, 246, 2, Pickering Passage/Squaxin Island	rural	30	11.5	silty sand	gray brown	none	14	none
14, 247, 3, Pickering Passage/Squaxin Island	rural	30	13	sand, shell	gray brown	none	5	none
15, 248, 1, Henderson Inlet	rural	30	11.5	silty-clay	olive black	slight sulfur	17	none
15, 249, 2, Henderson Inlet	rural	30	12	silt-clay	olive over black	strong sulfur	17	
15, 250, 3, Henderson Inlet	rural	Not Recorded	Not Recorded	silt-clay	olive over black	strong sulfur	17	
16, 251, 1, Case Inlet	rural	30	11	silt-clay	gray brown	none	17	3
16, 252, 2, Case Inlet	rural	30	11	silt-clay	gray brown	none	17	none
16, 253, 3, Case Inlet	rural	30	11	silt-clay	gray brown	none	17	none
17, 254, 1, Nisqually Reach	rural	31	11	sand	gray brown	none	4	none
17, 255, 2, Nisqually Reach	rural	30	11	silty sand	gray brown	none	17	none
17, 256, 3, Nisqually Reach	rural	30	11	silty sand	gray brown	none	12	none
18, 257, 1, Drayton Passage	rural	30	11	silt-clay	gray brown	none	16	2
18, 258, 2, Drayton Passage	rural	30	11.5	sand	brown	none	6	none
18, 259, 3, Drayton Passage	rural	30	11	sand, silt-clay	olive brown	none	11	none
19, 260, 1, East Anderson Island/No. Cormorant Passage	rural	30	11	silt-clay	olive gray	none	17	none
19, 261, 2, East Anderson Island/No. Cormorant Passage	rural	30.5	11.5	silty sand	gray brown	none	12	none
19, 262, 3, East Anderson Island/No. Cormorant Passage	rural/suburban	30	11	silty sand	gray brown	none	12	none
20, 263, 1, Carr Inlet	rural	30	10.5	silty sand	olive gray brown	none	14	none
20, 264, 2, Carr Inlet	rural	30	11	silt-clay	olive gray	none	17	none

Appendix F. Continued.

Stratum, Sample, Station, Location	Station Description	Salinity (ppt)	Temperature (°C)	Sediment Type	Sediment Color	Sediment Odor and intensity	Penetration depth (cm)	RPD (cm)
20, 265, 3, Carr Inlet	rural	30	11	silt-clay	olive gray	slight sulfur	17	none
21, 266, 1, Hale Passage	rural	31	11.5	sand, shell	gray brown	none	5.5	none
21, 267, 2, Hale Passage	rural	30	11	sand	gray brown	none	6.5	none
21, 268, 3, Hale Passage	rural/suburban	31	10.5	sand	gray brown	none	6	none
22, 269, 1, Gig Harbor	suburban	32	11.5	sand, silt-clay	gray	none	5	none
22, 270, 2, Gig Harbor	suburban	32	11.5	sand, silt-clay, plant fragments	olive over black	none	9	1-2
22, 271, 3, Gig Harbor	residential	32	11.5	silt-clay, wood, shell	olive over black	slight sulfur	14	1-2
23, 272, 1, Colvos Passage	rural	32	10.75	sand	brown	none	10	none
23, 273, 2, Colvos Passage	suburban	23	11	gravel, sand	brown	none	6	none
23, 274, 3, Colvos Passage	rural	32	10.75	sand	brown	none	9	none
24, 275, 1, Quartermaster Harbor	rural	30	12	sand	brown	none	8.5	none
24, 276, 2, Quartermaster Harbor	rural	30	12	silt-clay	brown over gray	none	16	1-2
24, 277, 3, Quartermaster Harbor	rural	30	12	silt-clay, wood, shell	brown over gray	none	14	1-2
25, 278, 1, East Passage	suburban	30	10	silt-clay, wood	brown over gray	none	17	0
25, 279, 2, East Passage	urban/suburban	30	10.5	silt-clay	gray	none	17	none
25, 280, 3, East Passage	rural	30	11	sand	brown	none	8	none
26, 281, 1, Outer Commencement Bay	urban/suburban	29	11	silt-clay	gray	none	17	none
26, 282, 2, Outer Commencement Bay	urban	23	11	Not Recorded	brown over gray	none	16.5	0
26, 283, 3, Outer Commencement Bay	urban/suburban	29	11	sand, silt-clay, wood, shell, plant fragments	gray brown	none	16	none
26, 284, 4, Outer Commencement Bay	urban	29	12	silty sand, wood	gray brown	none	12	Not Recorded

Appendix F. Continued.

Stratum, Sample, Station, Location	Station Description	Salinity (ppt)	Temperature (°C)	Sediment Type	Sediment Color	Sediment Odor and intensity	Penetration depth (cm)	RPD (cm)
27, 285, 1, S. E. Commencement Bay (shoreline)	urban	30	11	sand	brown	none	7	none
27, 286, 2, S. E. Commencement Bay (shoreline)	urban	27	11	silt-clay, wood	gray brown	none	17	none
27, 287, 3, S. E. Commencement Bay (shoreline)	urban	27	12	silty sand, wood	gray brown	slight sulfur	13.5	Not Recorded
28, 288, 1, S. E. Commencement Bay	urban	31	11	silt-clay, wood	olive over gray	none	10	1-2mm
28, 289, 2, S. E. Commencement Bay	urban	30	10	wood	olive over gray	none	15	1-2 mm
28, 290, 3, S. E. Commencement Bay	urban	30	11	silt-clay, wood, plant fragments	brown over gray	none	11	11
29, 291, 1, N.E. Commencement Bay	urban/suburban	28	11	slit-clay	gray	none	16	none
29, 292, 2, N.E. Commencement Bay	urban/suburban	29	11	Not Recorded	brown over gray	slight sulfur	15	none
29, 293, 3, N.E. Commencement Bay	urban	25	11.5	silt-clay, plant fragments	brown	moderate sulfur	15	none
30, 294, 1, Thea Foss Waterway	urban	23	14	silt-clay, plant fragments	black	strong sulfur	15	none
30, 295, 2, Thea Foss Waterway	urban	30	11	sand, silt-clay, wood, shell	brown over gray	none	15	1.5
30, 296, 3, Thea Foss Waterway	urban	31	11	sand, silt-clay, wood, shell	brown over gray	none	13	1
31, 297, 1, Middle Waterway	urban	31	11.5	silt-clay, wood	brown over gray	slight sulfur	11	.5
31, 298, 2, Middle Waterway	urban	31	12	sand, silt-clay, wood, shell	brown gray	none	9	.5

Appendix F. Concluded.

Stratum, Sample, Station, Location	Station Description	Salinity (ppt)	Temperature (°C)	Sediment Type	Sediment Color	Sediment Odor and intensity	Penetration depth (cm)	RPD (cm)
31, 299, 3, Middle Waterway	urban	31	11	gravel, silt-clay, wood	brown over gray	strong petroleum	10	surface washed
32, 300, 1, Blair Waterway	urban	30	11	silt-clay	olive black	none	14	0.5
32, 301, 2, Blair Waterway	urban	30	11	silt-clay	olive	none	12	0.5
32, 302, 3, Blair Waterway	urban	30	11	silt-clay	olive	none	12.5	none
33, 303, 1, Hylebos Waterway	urban	28	11	silt-clay	brown over black	none	14	<0.5
33, 304, 2, Hylebos Waterway	urban	28	12	silt-clay, wood	olive over black	none	11.5	none
33, 305, 3, Hylebos Waterway	urban	29	11	silt-clay	olive over black	none	14	<0.5

Appendix G

Chemistry data summary.

Table 1. Grain size distribution for the 1999 southern Puget Sound sampling stations (tabular form).

Table 2. Total organic carbon, temperature, and salinity measurements for the 1999 southern Puget Sound sampling stations.

Table 3. Summary statistics for metals and organics data.

Figure 1. Grain size distribution for the 1999 southern Puget Sound sampling stations (frequency distribution).

Appendix G, Table 1. Grain size distribution for the 1999 southern Puget Sound sampling stations (grain size in fractional percent).

Stratum, Location	Sample	Station	% Solids[3]	% Gravel	% Very Coarse Sand	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Fine Sand	Total % Sand	% Silt	% Clay	% Fines (Silt-Clay)
				>2000 mm	2000-1000 mm	1000-500 mm	500-250 mm	250-125 mm	125-62.5 mm	2000-62.5 mm	62.5-3.9 mm	<3.9 mm	
1, Port Ludlow	206	1	40.1	0.9	5.6	5.4	0.0	1.5	3.6	16.1	64.5	18.5	83.0
	207	2	74.3	0.1	1.5	8.7	25.2	32.1	19.6	87.1	10.2	2.6	12.8
	208	3	66.5	0.7	2.0	8.0	27.9	36.6	13.0	87.4	10.4	1.5	11.9
2, Hood Canal (north)	209	1	62.4	0.0	0.4	1.1	1.3	35.7	40.3	78.7	15.1	6.1	21.3
	210	2	64.5	0.1	0.2	0.4	1.0	14.7	64.1	80.3	15.0	4.6	19.6
	211	3	74.5	0.1	0.7	8.8	36.1	44.9	4.6	95.1	2.9	1.8	4.8
3, Port Gamble Bay	212	1	69.7	0.0	0.2	1.2	12.0	63.6	12.2	89.3	7.2	3.6	10.7
	213	2	72.4	0.6	0.6	4.2	30.9	49.8	6.1	91.5	5.7	2.2	7.9
	214	3	32.2	0.7	5.5	5.0	5.4	5.2	11.1	32.2	49.1	18.1	67.1
4, Quilcene Bay	216	2	59.1	0.1	0.3	3.1	12.4	35.3	18.0	69.1	25.4	5.4	30.9
	217	3	57.6	0.2	1.2	4.2	8.8	15.6	30.6	60.5	32.7	6.6	39.3
	215*	1	38.4	0.2	1.9	2.7	7.2	7.5	9.3	28.7	60.6	10.5	71.1
5, Dabob Bay	218	1	50.8	0.1	0.4	2.6	4.9	6.2	16.3	30.4	59.8	9.6	69.4
	219	2	22.2	0.0	0.2	4.7	2.3	0.7	0.6	8.4	47.5	44.1	91.6
	220	3	22.9	0.0	0.0	5.6	2.4	0.6	0.5	9.0	46.8	44.1	91.0
6, Hood Canal (central)	221	1	24.9	1.0	8.2	3.0	1.2	0.7	0.6	13.6	49.4	36.0	85.4
	222	2	41.1	0.4	1.6	6.1	9.4	8.1	10.8	36.0	47.1	16.5	63.6
	223	3	28.0	0.0	0.7	0.9	1.0	0.5	0.8	4.0	49.0	47.0	96.0
7, Hood Canal (south)	224	1	24.3	32.3	4.5	1.7	1.1	0.8	0.5	8.6	41.5	17.6	59.1
	225	2	22.6	15.2	8.9	2.1	1.0	0.6	0.5	13.1	50.7	21.0	71.7
	226	3	33.6	6.3	8.5	2.5	0.9	0.6	0.7	13.2	55.8	24.7	80.5
8, Port of Shelton	227	1	45.5	1.0	1.1	4.0	7.9	23.0	24.2	60.2	29.8	9.0	38.8

Appendix G, Table 1. Continued.

Stratum, Location	Sample	Station	% Solids	% Gravel	% Very Coarse Sand	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Fine Sand	Total % Sand	% Silt	% Clay	% Fines (Silt-Clay)
				>2000 mm	2000-1000 mm	1000-500 mm	500-250 mm	250-125 mm	125-62.5 mm	2000-62.5 mm	62.5-3.9 mm	<3.9 mm	
	228	2	46.3	0.1	0.4	2.0	3.5	16.5	27.6	50.0	38.2	11.7	49.9
	229	3	53.4	4.8	2.7	4.5	16.8	32.3	19.6	75.9	14.4	5.0	19.3
9, Oakland Bay	230	1	43.2	0.8	1.1	3.2	4.1	15.1	25.8	49.4	36.5	13.4	49.9
	231	2	34.7	0.2	0.8	7.9	3.9	2.5	8.1	23.2	51.8	24.9	76.6
	232	3	34.9	0.3	0.9	8.4	3.9	2.8	8.8	24.7	50.7	24.2	75.0
10, Totten Inlet	233	1	32.7	0.2	4.5	4.6	4.4	8.5	10.5	32.5	46.1	21.2	67.3
	234	2	29.6	0.0	6.3	3.1	1.0	0.6	1.8	12.9	58.5	28.6	87.1
	235	3	31.2	0.0	4.5	4.5	3.0	7.7	11.6	31.2	46.0	22.8	68.8
11, Eld Inlet	238	1	28.1	0.3	6.4	3.3	1.1	1.2	3.0	14.9	59.0	25.7	84.8
	239	2	30.5	0.0	3.7	2.9	1.3	1.2	4.8	13.9	63.9	22.1	86.1
	240	3	26.2	5.4	9.3	3.2	1.4	1.3	2.2	17.3	54.2	23.1	77.3
12, Budd Inlet	236	1	27.4	0.8	8.4	3.6	0.9	0.6	1.2	14.6	54.9	29.7	84.6
	237	2	31.5	0.0	1.8	2.5	1.5	2.0	6.3	14.1	62.0	23.9	85.9
	241	3	31.5	0.0	2.6	2.6	1.3	2.2	8.8	17.5	56.7	25.8	82.5
13, Port of Olympia	243	2	30.1	0.2	0.2	4.2	7.2	4.3	5.5	21.5	62.5	15.8	78.3
	244	3	40.9	0.0	0.1	1.8	2.8	15.7	24.0	44.5	42.9	12.6	55.5
	242*	1	23.4	0.0	0.2	8.2	7.1	3.8	2.5	21.8	57.5	20.8	78.2
14, Pickering Passage/Squaxin Island	245	1	74.4	16.7	8.9	13.4	32.2	21.0	2.9	78.3	3.2	1.8	5.0
	246	2	64.1	0.1	0.4	1.4	6.6	63.0	12.1	83.6	9.2	7.1	16.3
	247	3	67.0	24.6	16.5	10.6	24.7	14.6	1.2	67.6	4.9	3.0	7.9
15, Henderson Inlet	248	1	32.9	0.0	0.8	1.8	1.0	0.9	2.6	7.1	71.1	21.8	92.9
	249	2	30.9	0.1	0.7	1.4	1.7	1.1	2.5	7.3	67.4	25.1	92.5
	250	3	28.7	0.0	1.7	2.0	1.1	0.7	1.7	7.2	67.7	25.1	92.8
16, Case Inlet	251	1	37.7	0.6	0.6	1.8	2.2	3.0	18.1	25.7	51.7	22.1	73.7

Appendix G, Table 1. Continued.

Stratum, Location	Sample	Station	% Solids	% Gravel >2000 mm	% Very Coarse Sand 2000-1000 mm	% Coarse Sand 1000-500 mm	% Medium Sand 500-250 mm	% Fine Sand 250-125 mm	% Very Fine Sand 125-62.5 mm	Total % Sand 2000-62.5 mm	% Silt 62.5-3.9 mm	% Clay <3.9 mm	% Fines (Silt-Clay)
	252	2	32.2	0.0	0.2	2.5	2.5	1.6	4.8	11.7	60.4	27.9	88.3
	253	3	33.5	0.0	0.2	6.4	3.7	3.0	4.7	18.0	54.7	27.3	82.0
17, Nisqually Reach	254	1	69.4	0.1	0.1	0.3	9.4	62.7	18.5	91.1	6.2	2.7	8.8
	255	2	48.7	0.3	0.3	1.1	1.8	11.1	39.7	53.9	31.7	14.1	45.8
	256	3	63.9	0.1	0.3	0.4	1.4	42.0	35.3	79.5	14.4	6.1	20.4
18, Drayton Passage	257	1	43.1	0.0	0.6	1.5	1.5	2.6	21.8	28.0	53.8	18.2	72.0
	258	2	71.3	0.0	0.1	2.8	33.0	56.6	2.3	94.9	3.0	2.1	5.1
	259	3	68.4	0.1	0.5	6.1	32.7	23.8	17.4	80.5	15.0	4.5	19.5
19, East Anderson Island/No. Cormorant	260	1	46.0	0.0	0.6	1.2	3.2	20.4	31.9	57.3	28.1	14.6	42.7
	261	2	56.6	0.0	0.4	1.4	4.6	38.5	31.3	76.2	15.0	8.7	23.8
	262	3	67.2	0.0	0.3	0.7	8.7	64.3	14.1	88.1	8.1	3.8	11.9
20, Carr Inlet	263	1	64.6	0.0	0.3	2.8	12.8	35.7	30.0	81.6	12.7	5.6	18.4
	264	2	29.7	0.0	4.6	4.6	2.8	1.3	3.0	16.3	52.2	31.5	83.7
	265	2	28.7	0.1	9.7	4.5	3.1	2.9	3.6	23.8	47.3	28.8	76.1
21, Hale Passage	266	1	75.4	2.1	3.1	13.4	44.3	28.5	3.5	92.8	3.8	1.4	5.1
	267	2	72.9	0.1	0.7	6.9	26.0	40.5	17.9	92.1	5.2	2.6	7.8
	268	3	75.7	0.0	0.7	16.5	44.9	34.6	1.1	97.9	1.4	0.7	2.0
22, Gig Harbor	269	1	64.2	0.1	0.6	3.8	20.2	28.8	18.8	72.4	20.2	7.4	27.6
	270	2	62.4	0.6	2.7	8.8	28.3	27.2	9.6	76.4	14.0	9.0	22.9
	271	3	48.8	0.0	1.2	1.7	5.6	12.9	20.9	42.4	46.9	10.7	57.6
23, Colvos Passage	272	1	68.7	0.1	0.2	0.6	2.4	70.3	18.7	92.2	4.1	3.6	7.8
	273	2	68.9	1.9	1.3	5.8	51.9	36.8	2.4	95.8	2.0	0.4	2.4
	274	3	71.3	0.4	0.4	1.4	29.6	56.6	4.8	92.7	4.2	2.7	6.9
24, Quartermaster	275	1	73.0	0.0	0.4	0.3	33.3	45.1	9.9	89.1	7.6	3.2	10.9

Appendix G, Table 1. Continued.

Stratum, Location	Sample	Station	% Solids	% Gravel	% Very Coarse Sand	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Fine Sand	Total % Sand	% Silt	% Clay	% Fines (Silt-Clay)
				>2000 mm	2000-1000 mm	1000-500 mm	500-250 mm	250-125 mm	125-62.5 mm	2000-62.5 mm	62.5-3.9 mm	<3.9 mm	
Harbor	276	2	33.2	0.4	6.1	3.5	3.5	2.4	4.5	20.1	59.4	20.1	79.5
	277	3	47.1	0.1	0.7	1.6	3.0	5.1	28.1	38.5	49.5	11.9	61.4
25, East Passage	278	1	49.5	2.1	3.5	4.4	7.5	21.4	27.7	64.5	21.0	12.3	33.4
	279	2	31.6	0.0	0.0	3.4	4.7	2.3	4.4	14.8	49.8	35.4	85.2
	280	3	77.5	0.4	1.2	13.2	56.0	25.4	1.6	97.5	1.7	0.5	2.1
26, Outer	281	1	43.1	0.0	0.0	1.0	1.7	1.2	5.0	8.9	67.5	23.6	91.1
Commencement	282	2	48.4	0.0	0.1	1.4	3.8	7.4	15.4	28.0	54.5	17.5	72.0
Bay	283	3	47.7	0.0	0.0	2.0	4.9	10.0	14.5	31.3	49.5	19.2	68.7
	284	4	62.3	0.3	0.2	1.2	22.2	43.9	13.4	80.9	12.9	5.9	18.8
27, S. E.	285	1	71.1	0.1	1.0	7.5	31.5	40.8	8.8	89.5	7.4	3.0	10.4
Commencement	286	2	56.5	2.0	2.9	5.0	9.1	25.2	16.5	58.8	27.1	12.1	39.2
Bay (shoreline)	287	3	51.9	1.1	1.2	3.9	8.3	12.5	24.9	50.8	41.2	6.9	48.1
28, S. E.	289	2	49.1	0.0	0.2	1.1	1.7	6.0	26.5	35.5	52.3	12.2	64.5
Commencement	290	3	41.8	0.0	0.1	0.8	1.4	3.2	15.8	21.3	62.6	16.1	78.7
Bay	288*	1	43.6	0.1	0.0	1.0	1.7	3.1	13.1	18.9	65.9	15.1	81.0
29, N.E.	291	1	45.0	0.0	0.0	1.7	2.3	1.5	4.7	10.2	67.8	22.0	89.8
Commencement	292	2	52.6	0.0	0.1	1.1	2.2	1.6	7.7	12.6	66.9	20.4	87.4
Bay	293	3	47.7	0.6	0.5	3.9	6.0	4.4	3.5	18.3	50.3	30.9	81.1
30, Thea Foss	294	1	30.5	4.8	2.5	6.9	10.7	9.6	7.8	37.5	44.2	13.5	57.7
Waterway	295	2	54.1	0.1	0.2	2.6	6.9	12.9	11.5	34.0	48.6	17.2	65.8
	296	3	54.5	0.1	0.2	1.7	6.6	12.7	12.7	33.9	49.6	16.4	66.1
31, Middle	297	1	48.4	2.3	0.9	2.3	5.0	9.4	15.0	32.7	52.6	12.4	65.0
Waterway	298	2	59.3	7.5	2.0	8.8	23.4	22.5	11.9	68.6	19.0	4.9	23.9
	299	3	58.7	1.5	1.7	6.7	15.4	15.0	12.1	50.9	35.7	11.9	47.6

Appendix G, Table 1. Concluded.

Stratum, Location	Sample	Station	% Solids	% Gravel	% Very Coarse Sand	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Fine Sand	Total % Sand	% Silt	% Clay	% Fines (Silt-Clay)
				>2000 mm	2000-1000 mm	1000-500 mm	500-250 mm	250-125 mm	125-62.5 mm	2000-62.5 mm	62.5-3.9 mm	<3.9 mm	
32, Blair Waterway	300	1	57.3	0.2	0.1	0.7	2.7	8.5	15.9	27.9	54.1	17.8	71.9
	301	2	59.5	0.0	0.1	1.4	6.7	11.3	13.1	32.6	51.9	15.5	67.4
	302	3	63.0	1.1	1.9	8.5	15.9	14.8	8.6	49.6	35.2	14.1	49.3
33, Hylebos Waterway	303*	1	46.7	0.4	1.1	2.2	6.2	8.6	10.0	28.1	45.8	25.7	71.5
	304	2	59.2	1.6	1.0	5.2	16.5	18.7	8.3	49.7	32.8	15.9	48.7
	305	3	49.3	10.3	3.9	1.9	3.9	7.3	6.7	23.7	40.1	25.8	66.0

* mean of three lab replicates.

Appendix G, Table 2. Total organic carbon, temperature, and salinity measurements for the 1999 southern Puget Sound sampling stations.

Stratum Number	Location	Sample Number	Salinity (ppt)	Temperature (°C)	% TOC
1	Port Ludlow	206	30.0	11.0	0.58
		207	30.0	12.0	0.36
		208	30.0	14.0	2.30
2	Hood Canal (north)	209	30.0	11.0	0.59
		210	30.0	11.0	0.48
		211	31.0	11.5	0.26
3	Port Gamble Bay	212	30.0	12.0	0.53
		213	30.0	13.5	0.37
		214	30.0	12.0	4.40
4	Quilcene Bay	215	25.0	11.0	3.20
		216	27.0	12.0	1.30
		217	30.0	11.0	1.40
5	Dabob Bay	218	29.0	11.0	1.40
		219	25.0	12.0	2.70
		220	27.0	12.0	2.70
6	Hood Canal (central)	221	25.0	12.0	2.40
		222	30.0	11.5	1.60
		223	27.0	12.0	2.70
7	Hood Canal (south)	224	24.0	11.5	3.80
		225	25.0	11.5	4.20
		226	25.0	11.0	2.00
8	Port of Shelton	227	27.0	15.0	2.60
		228	25.0	15.0	2.40
		229	25.0	14.5	1.50
9	Oakland Bay	230	27.0	13.0	2.60
		231	27.0	14.5	3.10

Appendix G, Table 2. Continued.

Stratum Number	Location	Sample Number	Salinity (ppt)	Temperature (°C)	% TOC
		232	27.0	14.0	3.30
10	Totten Inlet	233	30.0	14.0	2.40
		234	28.0	13.5	2.70
		235	30.0	13.0	2.30
11	Eld Inlet	238	30.0	12.0	2.60
		239	30.0	12.0	2.30
		240	30.0	12.0	2.90
12	Budd Inlet	236	30.0	12.0	3.00
		237	30.0	12.0	2.40
		241	30.0	11.8	2.30
13	Port of Olympia	242	30.0	12.0	3.90
		243	30.0	12.0	3.80
		244	31.0	13.0	2.40
14	Pickering Passage/Squaxin Island	245	30.0	13.0	0.24
		246	30.0	11.5	0.56
		247	30.0	13.0	0.31
15	Henderson Inlet	248	30.0	11.5	2.60
		249	30.0	12.0	2.90
		250	Not Recorded	Not Recorded	3.10
16	Case Inlet	251	30.0	11.0	1.70
		252	30.0	11.0	2.10
		253	30.0	11.0	2.10
17	Nisqually Reach	254	31.0	11.0	0.24
		255	30.0	11.0	1.10
		256	30.0	11.0	0.58
18	Drayton Passage	257	30.0	11.0	1.30
		258	30.0	11.5	0.20
		259	30.0	11.0	0.38

Appendix G, Table 2. Continued.

Stratum Number	Location	Sample Number	Salinity (ppt)	Temperature (°C)	% TOC
19	East Anderson Island/No. Cormorant Passage	260	30.0	11.0	1.30
		261	30.5	11.5	0.69
		262	30.0	11.0	0.40
20	Carr Inlet	263	30.0	10.5	0.46
		264	30.0	11.0	2.50
		265	30.0	11.0	2.60
21	Hale Passage	266	31.0	11.5	0.12
		267	30.0	11.0	0.25
		268	31.0	10.5	0.07
22	Gig Harbor	269	32.0	11.5	0.88
		270	32.0	11.5	1.00
		271	32.0	11.5	1.90
23	Colvos Passage	272	32.0	10.8	0.33
		273	23.0	11.0	0.15
		274	32.0	10.8	0.22
24	Quartermaster Harbor	275	30.0	12.0	0.27
		276	30.0	12.0	2.50
		277	30.0	12.0	1.30
25	East Passage	278	30.0	10.0	3.90
		279	30.0	10.5	2.30
		280	30.0	11.0	0.06
26	Outer Commencement Bay	281	29.0	11.0	1.60
		282	23.0	11.0	1.40
		283	29.0	11.0	1.40
		284	29.0	12.0	0.50
27	S. E. Commencement Bay (shoreline)	285	30.0	11.0	0.48
		286	27.0	11.0	1.10
		287	27.0	12.0	2.30

Appendix G, Table 2. Concluded.

Stratum Number	Location	Sample Number	Salinity (ppt)	Temperature (°C)	% TOC
28	S. E. Commencement Bay	288	31.0	11.0	1.70
		289	30.0	10.0	1.70
		290	30.0	11.0	1.80
29	N.E. Commencement Bay	291	28.0	11.0	1.50
		292	29.0	11.0	1.80
		293	25.0	11.5	2.20
30	Thea Foss Waterway	294	23.0	14.0	7.90
		295	30.0	11.0	2.30
		296	31.0	11.0	2.20
31	Middle Waterway	297	31.0	11.5	1.90
		298	31.0	12.0	1.30
		299	31.0	11.0	1.40
32	Blair Waterway	300	30.0	11.0	0.87
		301	30.0	11.0	0.93
		302	30.0	11.0	1.00
33	Hylebos Waterway	303	28.0	11.0	2.70
		304	28.0	12.0	1.10
		305	29.0	11.0	2.20
		minimum	23.0	10.0	0.1
		maximum	32.0	15.0	7.9
		median	30.0	11.5	1.7
		mean	29.1	11.7	1.8
		standard deviation	2.1	1.0	1.3

Appendix G, Table 3. 1999 summary statistics for metal and organic chemicals from 100 sediment samples from southern Puget Sound.

CHEMICAL (unit of measure)	MEAN	MEDIAN	MINIMUM	MAXIMUM	RANGE	N	NO. OF NONDETECTED VALUES	NO. OF MISSING VALUES
METALS (ppm, mg/kg dry wt)								
Ancillary Metals								
Aluminum*	12668.40	12200.00	4040.00	28600.00	24560.00	105	0	0
Aluminum**	58651.71	53600.00	4240.00	611000.00	606760.00	105	0	0
Barium*	21.99	21.80	6.88	60.40	53.52	105	0	0
Barium**	242.90	237.00	103.00	350.00	247.00	105	0	0
Calcium*	6946.38	5440.00	2180.00	80100.00	77920.00	105	0	0
Calcium**	16868.10	16300.00	4560.00	44200.00	39640.00	105	0	0
Cobalt*	7.48	6.78	1.40	20.10	18.70	105	0	0
Cobalt**	12.51	11.40	5.26	49.20	43.94	105	0	0
Iron*	20753.33	19900.00	6480.00	51900.00	45420.00	105	0	0
Iron**	34237.14	35600.00	11800.00	126000.00	114200.00	105	0	0
Magnesium*	7665.14	6930.00	2470.00	17900.00	15430.00	105	0	0
Magnesium**	7195.81	6770.00	2860.00	18400.00	15540.00	105	0	0
Manganese*	403.65	276.00	75.90	3040.00	2964.10	105	0	0
Manganese**	663.76	521.00	273.00	3330.00	3057.00	105	0	0
Potassium*	2041.55	1870.00	560.00	9600.00	9040.00	105	0	0
Potassium**	8554.67	8600.00	4000.00	15100.00	11100.00	105	0	0
Sodium*	13109.90	11200.00	3050.00	34300.00	31250.00	105	0	0
Sodium**	29569.52	28600.00	17500.00	63900.00	46400.00	105	0	0
Vanadium*	33.37	33.30	8.75	84.70	75.95	105	0	0
Vanadium**	104.71	100.00	41.00	453.00	412.00	105	0	0
Priority Pollutant Metals								
Antimony*	1.25	0.35	0.12	12.10	11.98	16	89	0
Antimony**	1.87	0.92	0.50	16.90	16.40	63	42	0
Arsenic*	8.17	7.39	2.00	57.40	55.40	105	0	0
Arsenic**	10.05	9.17	2.90	39.10	36.20	105	0	0
Beryllium*	1.40	1.19	0.38	4.55	4.17	105	0	0
Beryllium**	3.85	2.90	2.50	38.00	35.50	59	46	0

Appendix G, Table 3. Continued.

CHEMICAL (unit of measure)	MEAN	MEDIAN	MINIMUM	MAXIMUM	RANGE	N	NO. OF NONDETECTED VALUES	NO. OF MISSING VALUES
Cadmium*	0.56	0.39	0.10	2.31	2.21	72	33	0
Cadmium**	0.53	0.39	0.10	2.49	2.39	102	3	0
Chromium*	25.17	21.40	7.20	57.40	50.20	105	0	0
Chromium**	75.23	68.00	27.00	227.00	200.00	105	0	0
Copper*	41.03	34.40	0.75	418.00	417.25	105	0	0
Copper**	51.11	41.70	1.05	280.00	278.95	196	14	0
Lead*	20.63	13.90	2.15	262.00	259.85	105	0	0
Lead**	24.73	17.20	4.41	277.00	272.59	105	0	0
Mercury	0.13	0.08	0.01	1.55	1.54	105	0	0
Nickel*	24.35	22.90	7.00	50.50	43.50	105	0	0
Nickel**	30.72	29.50	15.10	90.30	75.20	105	0	0
Selenium*	0.58	0.50	0.31	1.50	1.19	68	37	0
Selenium**	0.67	0.60	0.31	1.75	1.44	73	32	0
Silver*	0.33	0.26	0.10	2.56	2.46	84	21	0
Silver**	0.65	0.45	0.25	4.49	4.24	64	41	0
Thallium*	0.18	0.15	0.10	0.38	0.28	48	57	0
Thallium**	0.30	0.28	0.20	0.53	0.33	87	18	0
Zinc*	63.22	60.80	15.30	315.00	299.70	105	0	0
Zinc**	83.60	82.00	18.00	309.00	291.00	105	0	0
Major Elements								
Silicon**	286394.29	274000.00	118000.00	461000.00	343000.00	105	0	0
Trace Elements								
Tin*	1.35	0.98	0.15	13.60	13.45	105	0	0
Tin**	2.07	1.66	0.38	14.90	14.52	103	2	0

* strong acid digestion
** hydrofluoric acid digestion

Organotins (ug/kg dry wt)								
Dibutyltin Dichloride	88.66	16.00	6.70	1300.00	1293.30	21	84	0
Monobutyltin Chloride	22.63	12.00	4.30	140.00	135.70	19	86	0

Appendix G, Table 3. Continued.

CHEMICAL (unit of measure)	MEAN	MEDIAN	MINIMUM	MAXIMUM	RANGE	N	NO. OF NONDETECTED VALUES	NO. OF MISSING VALUES
Monobutyltin Trichloride	22.63	12.00	4.30	140.00	135.70	19	86	0
Tetrabutyltin	87.48	47.00	6.40	430.00	423.60	26	184	0
Tributyltin Chloride	87.48	47.00	6.40	430.00	423.60	26	184	0
ORGANICS (ug/kg dry wt)								
Chlorinated Aromatic Compounds								
1,2,4-Trichlorobenzene	6.98	6.90	5.90	8.20	2.30	4	101	0
1,2-Dichlorobenzene	8.27	3.70	1.10	20.00	18.90	3	102	0
1,3-Dichlorobenzene	25.00	25.00	17.00	33.00	16.00	2	103	0
1,4-Dichlorobenzene	18.82	8.50	2.30	221.00	218.70	24	81	0
2-Chloronaphthalene						0	105	0
Hexachlorobenzene	5.72	1.00	0.49	27.00	26.51	19	86	0
Chlorinated Alkanes								
Hexachlorobutadiene	26.50	17.00	11.00	80.00	69.00	6	99	0
Chlorinated and Nitro-Substituted Phenols								
Pentachlorophenol	127.20	37.00	20.00	355.00	335.00	15	90	0
HPAHs								
Benzo(a)anthracene	181.14	32.00	0.94	5400.00	5399.06	105	0	0
Benzo(a)pyrene	217.59	40.50	1.50	5930.00	5928.50	104	1	0
Benzo(b)fluoranthene	131.28	57.00	1.10	4190.00	4188.90	102	3	0
Benzo(e)pyrene	146.47	39.00	0.75	3730.00	3729.25	105	0	0
Benzo(g,h,i)perylene	142.88	49.00	0.92	3280.00	3279.08	101	4	0
Benzo(k)fluoranthene	196.09	45.00	1.90	4630.00	4628.10	101	4	0
Chrysene	280.55	53.00	1.50	8160.00	8158.50	105	0	0
Dibenzo(a,h)anthracene	48.06	9.30	0.19	1200.00	1199.81	86	19	0
Fluoranthene	472.80	119.00	2.20	14600.00	14597.80	105	0	0
Indeno(1,2,3-c,d)pyrene	138.65	35.00	0.15	3330.00	3329.85	101	4	0
Perylene	124.08	85.00	2.40	1560.00	1557.60	105	0	0
Pyrene	568.04	133.00	1.80	18600.00	18598.20	105	0	0
C1-Chrysenes	175.05	59.00	1.40	5300.00	5298.60	105	0	0

Appendix G, Table 3. Continued.

CHEMICAL (unit of measure)	MEAN	MEDIAN	MINIMUM	MAXIMUM	RANGE	N	NO. OF NONDETECTED VALUES	NO. OF MISSING VALUES
C1-Fluoranthene/Pyrene	394.35	98.00	2.10	10300.00	10297.90	105	0	0
C2-Chrysenes						0	105	0
C3-Chrysenes	23.00	23.00	23.00	23.00	0.00	1	104	0
C4-Chrysenes						0	105	0
LPAHs								
1,6,7-Trimethylnaphthalene	48.93	20.00	0.98	643.00	642.02	105	0	0
1-Methylnaphthalene	55.44	21.00	0.87	1020.00	1019.13	104	1	0
1-Methylphenanthrene	52.24	19.00	0.09	930.00	929.91	105	0	0
2,6-Dimethylnaphthalene	53.37	34.00	0.54	751.00	750.46	105	0	0
2-Methylnaphthalene	87.49	29.00	1.50	2340.00	2338.50	103	2	0
2-Methylphenanthrene	70.61	27.00	0.98	1350.00	1349.02	105	0	0
Acenaphthene	65.50	10.35	0.41	2450.00	2449.59	96	9	0
Acenaphthylene	55.40	11.00	0.18	1190.00	1189.82	105	0	0
Anthracene	135.17	22.00	0.37	4160.00	4159.63	104	1	0
Biphenyl	92.56	13.50	1.00	1780.00	1779.00	90	15	0
Dibenzothiophene	25.88	5.20	0.11	586.00	585.89	103	2	0
Fluorene	71.08	16.00	0.06	2260.00	2259.94	103	2	0
Naphthalene	282.27	50.00	3.10	7340.00	7336.90	100	5	0
Phenanthrene	357.72	83.00	2.00	10900.00	10898.00	105	0	0
Retene	437.49	175.00	5.50	8360.00	8354.50	105	0	0
C1-Dibenzothiophenes	0.91	0.91	0.71	1.10	0.39	2	103	0
C1-Fluorenes	68.92	23.00	1.30	1720.00	1718.70	101	4	0
C1-Naphthalenes	156.42	51.00	4.80	4110.00	4105.20	102	3	0
C1-Phenanthrenes/Anthracenes	293.55	96.00	2.90	6380.00	6377.10	105	0	0
C2 -Naphthalenes	147.49	81.00	1.60	2130.00	2128.40	105	0	0
C2-Dibenzothiophenes	18.27	5.40	0.32	666.00	665.68	103	2	0
C2-Fluorenes	27.79	17.00	1.70	87.00	85.30	7	98	0
C2-Phenanthrenes/Anthracenes	295.36	95.50	4.80	5160.00	5155.20	104	1	0
C3 -Naphthalenes	210.22	107.00	3.30	2520.00	2516.70	105	0	0
C3-Dibenzothiophenes	39.87	11.00	1.20	140.00	138.80	9	96	0
C3-Fluorenes						0	105	0
C3-Phenanthrenes/Anthracenes	41.08	16.00	0.15	527.00	526.85	68	37	0

Appendix G, Table 3. Continued.

CHEMICAL (unit of measure)	MEAN	MEDIAN	MINIMUM	MAXIMUM	RANGE	N	NO. OF NONDETECTED VALUES	NO. OF MISSING VALUES
C4 -Naphthalenes	5.70	5.70	5.70	5.70	0.00	1	104	0
C4-Phenanthrenes/Anthracenes	436.03	175.00	5.50	8360.00	8354.50	105	0	0
Miscellaneous Extractable Compounds								
Benzoic acid	329.32	178.00	71.00	1190.00	1119.00	41	64	0
Benzyl alcohol	58.56	40.00	21.00	146.00	125.00	9	96	0
Dibenzofuran	56.51	14.00	0.55	1440.00	1439.45	103	2	0
Organonitrogen Compounds								
9(H)Carbazole	21.33	4.10	0.16	629.00	628.84	103	2	0
N-nitrosodiphenylamine	15.60	15.60	5.20	26.00	20.80	2	103	0
Phenols								
2,4-Dimethylphenol	25.74	17.00	5.10	76.00	70.90	5	100	0
2-Methylphenol	11.02	11.50	2.10	22.00	19.90	12	93	0
4-Methylphenol	62.41	35.00	2.60	425.00	422.40	52	53	0
Phenol	1152.33	124.50	48.00	10500.00	10452.00	12	93	0
Phenol, 4-Nonyl-	21.87	23.00	9.60	33.00	23.40	3	102	0
Phthalate Esters								
Bis(2-Ethylhexyl) Phthalate	1097.00	841.50	120.00	4660.00	4540.00	8	97	0
Butylbenzylphthalate	53.76	44.95	0.35	128.00	127.65	6	99	0
Di-N-Butylphthalate	272.00	272.00	69.00	475.00	406.00	2	103	0
Di-N-Octyl Phthalate	21.27	24.00	6.80	33.00	26.20	3	102	0
Diethylphthalate	198.57	67.00	23.00	843.00	820.00	7	98	0
Dimethylphthalate	23.48	17.50	8.20	94.00	85.80	12	93	0
Chlorinated Pesticides								
2,4'-DDD	2.90	2.90	2.90	2.90	0.00	1	104	0
4,4'-DDD	2.27	1.30	0.54	7.84	7.30	15	90	0
2,4'-DDE						0	105	0
4,4'-DDE	3.58	0.96	0.54	18.00	17.46	14	91	0
2,4'-DDT						0	105	0

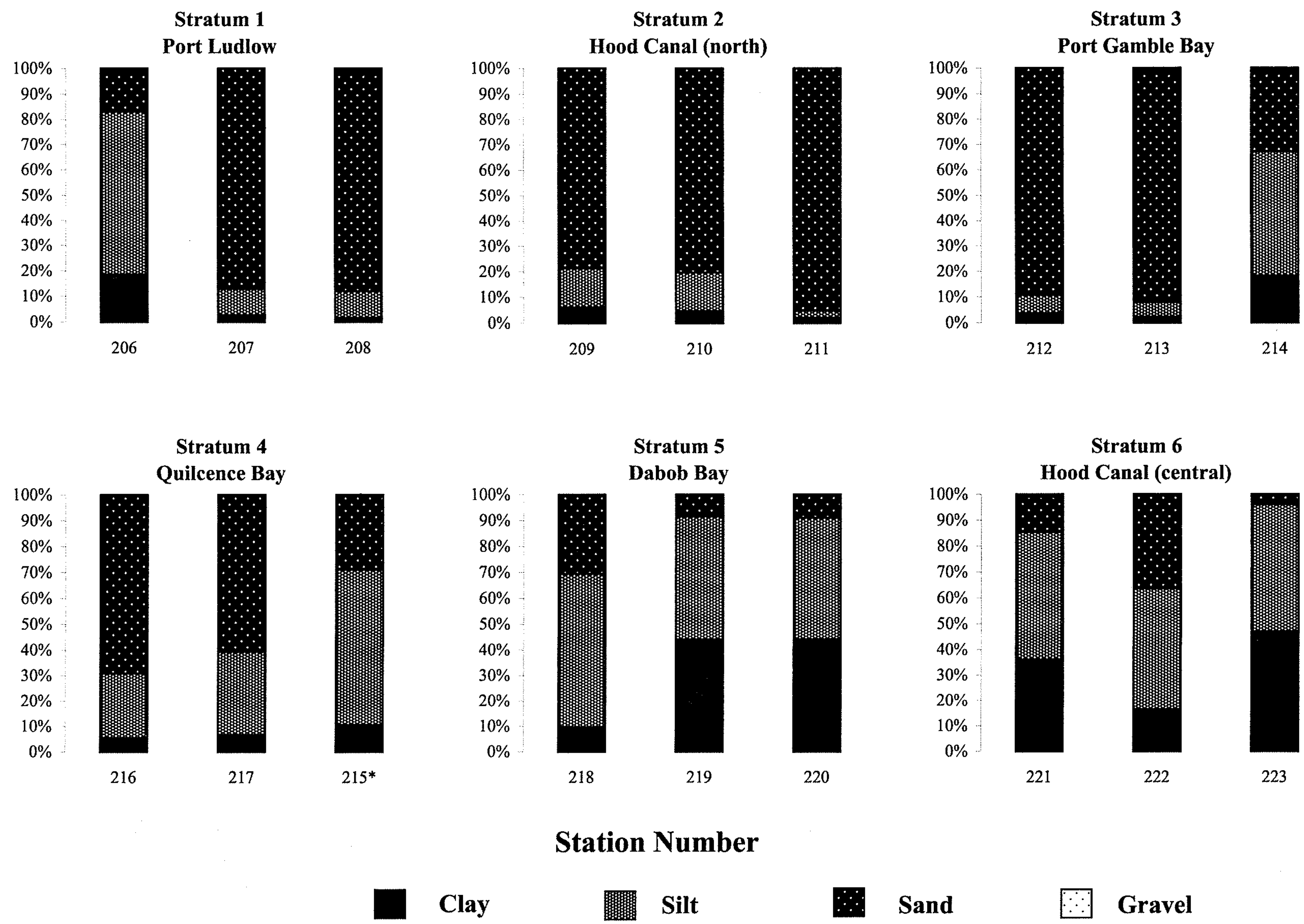
Appendix G, Table 3. Continued.

CHEMICAL (unit of measure)	MEAN	MEDIAN	MINIMUM	MAXIMUM	RANGE	N	NO. OF NONDETECTED VALUES	NO. OF MISSING VALUES
4,4'-DDT	2.90	1.60	0.67	8.70	8.03	9	96	0
Aldrin						0	105	0
Alpha-chlordane	1.05	1.05	0.33	1.70	1.37	8	97	0
Alpha-HCH (Alpha BHC)						0	105	0
Beta-HCH (Beta BHC)						0	105	0
Chlorpyrifos						0	0	105
Cis-nonachlor	0.85	0.85	0.60	1.10	0.50	3	102	0
Delta-HCH (Delta BHC)						0	105	0
Dieldrin	0.76	0.76	0.51	1.00	0.49	2	103	0
Endosulfan I (Alpha-endosulfan)	0.51	0.51	0.51	0.51	0.00	1	104	0
Endosulfan II (Beta-endosulfan)						0	105	0
Endo-sulfansulfate						0	105	0
Endrin	0.51	0.51	0.51	0.51	0.00	2	103	0
Endrin ketone	1.00	1.00	1.00	1.00	0.00	1	104	0
Endrin-aldehyde						0	0	105
Gamma-chlordane (Trans-Chlordane)	1.10	1.20	0.39	1.60	1.21	7	98	0
Gamma-HCH (Gamma BHC) (Lindan						0	105	0
Heptachlor						0	105	0
Heptachlor epoxide						0	105	0
Methoxychlor	2.00	2.00	2.00	2.00	0.00	1	104	0
Mirex						0	105	0
Oxychlordane	1.00	1.10	0.51	1.30	0.79	4	101	0
Toxaphene						0	105	0
Trans-nonachlor	1.74	1.47	0.69	3.34	2.65	4	101	0
Polycyclic Chlorinated Biphenyls								
PCB Arochlors:								
1016						0	104	0
1221						0	105	0
1232						0	105	0
1242						0	105	0
1248	41.18	12.70	5.50	230.00	224.50	10	95	0
1254	47.18	10.00	5.00	560.00	555.00	37	68	0

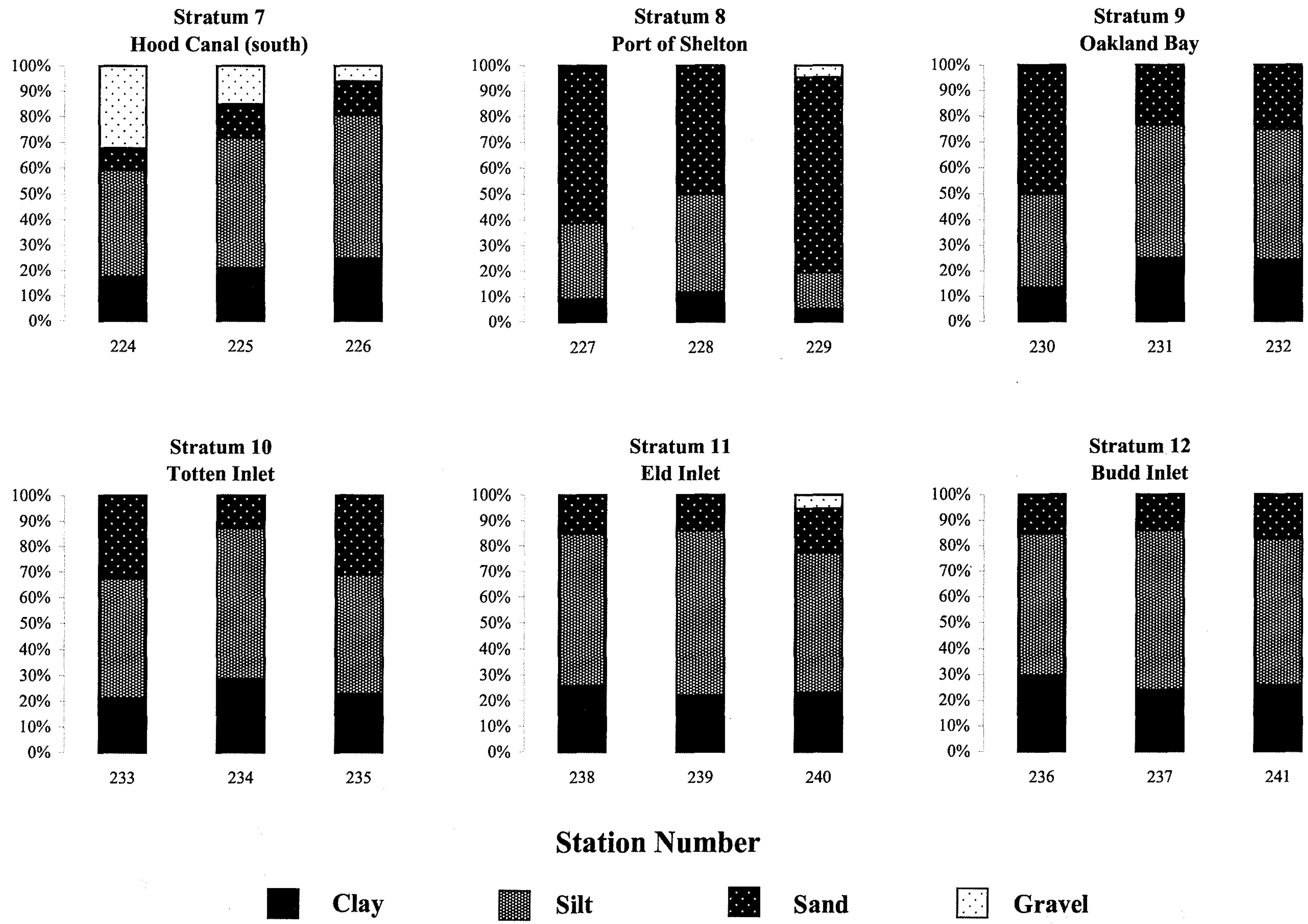
Appendix G, Table 3. Concluded.

CHEMICAL (unit of measure)	MEAN	MEDIAN	MINIMUM	MAXIMUM	RANGE	N	NO. OF NONDETECTED VALUES	NO. OF MISSING VALUES
1260	42.96	14.00	5.10	270.00	264.90	25	80	0
1262	27.22	25.45	6.60	49.00	42.40	6	194	0
1268	27.22	25.45	6.60	49.00	42.40	6	194	0
PCB Congeners:								
8	4.90	4.90	4.90	4.90	0.00	1	104	0
18	7.55	7.55	6.10	9.00	2.90	2	103	0
28	85.91	0.82	0.20	840.00	839.80	10	95	0
44	83.95	5.15	0.44	940.00	939.56	12	93	0
52	69.65	1.00	0.48	1400.00	1399.52	21	84	0
66	120.82	1.60	0.47	1300.00	1299.53	11	94	0
77	0.93	0.93	0.93	0.93	0.00	1	104	0
101	100.83	0.89	0.31	3600.00	3599.69	37	68	0
105	3.36	1.20	0.47	17.00	16.53	12	93	0
118	3.58	0.86	0.35	42.00	41.65	31	74	0
126	0.94	0.94	0.68	1.20	0.52	2	103	0
128	2.75	1.40	0.55	15.00	14.45	13	92	0
138	3.58	0.95	0.40	45.00	44.60	43	62	0
153	3.34	0.87	0.41	41.00	40.59	47	58	0
170	3.05	2.05	0.43	17.00	16.57	16	89	0
180	4.11	1.20	0.20	26.00	25.80	23	82	0
187	3.38	0.97	0.20	17.90	17.70	21	84	0
195	0.93	0.52	0.49	2.97	2.48	6	99	0
206	5.11	1.30	0.52	16.20	15.68	16	89	0
209	7.31	1.40	0.29	35.00	34.71	16	89	0

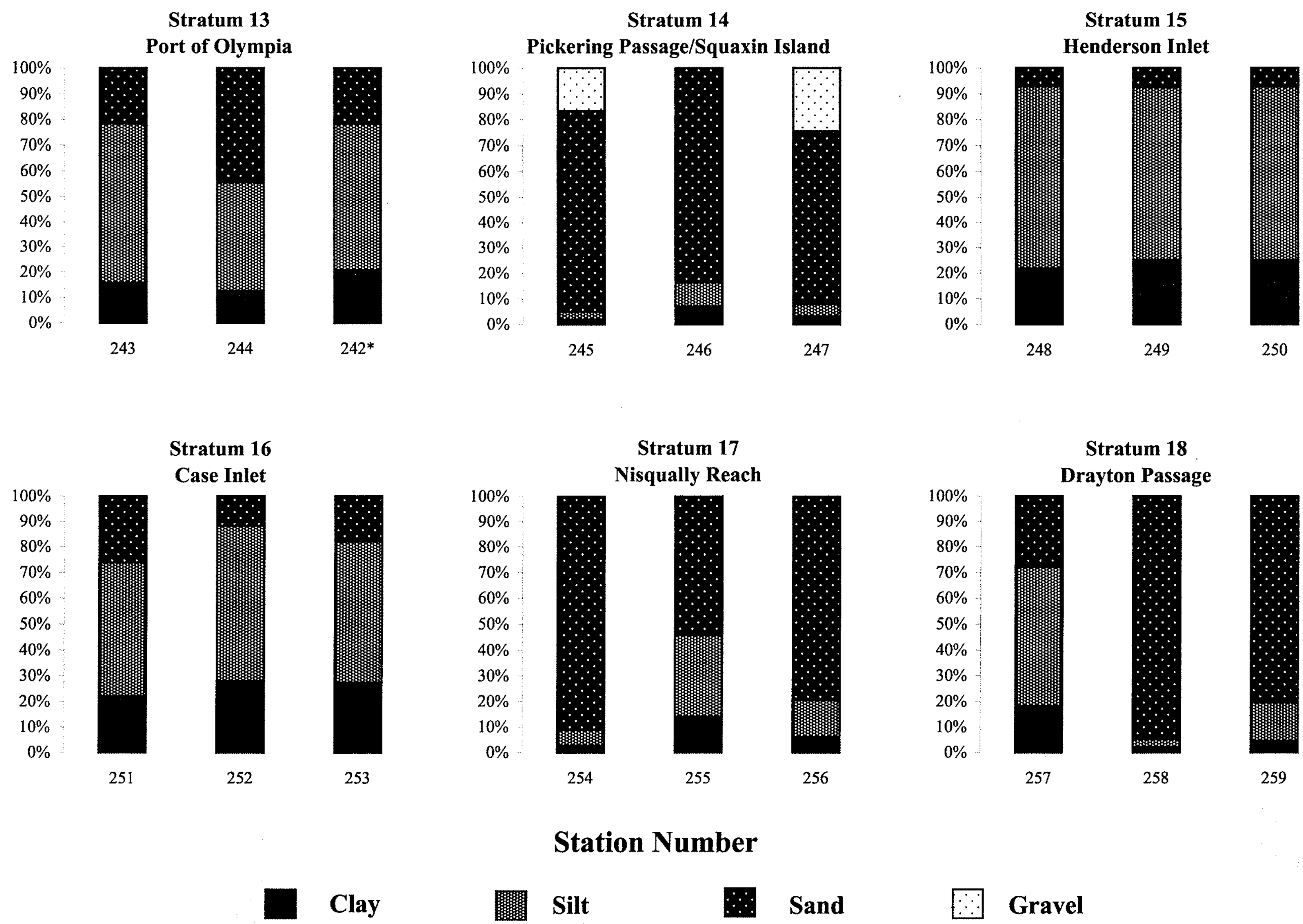
Appendix G, Figure 1. Grain size distribution for the 1999 southern Puget Sound sampling stations (grain size in fractional percent).



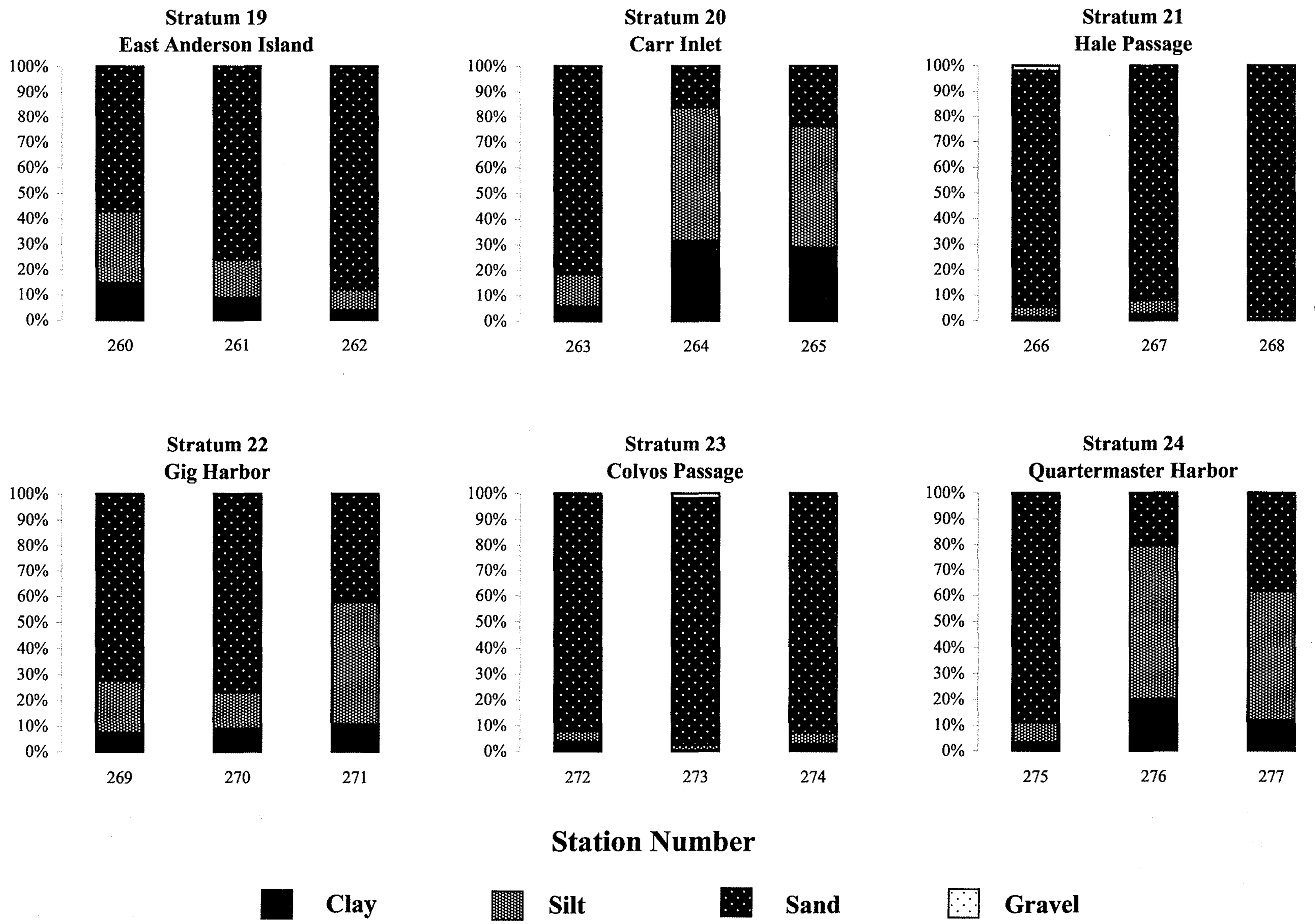
Appendix G, Figure 1. Continued.



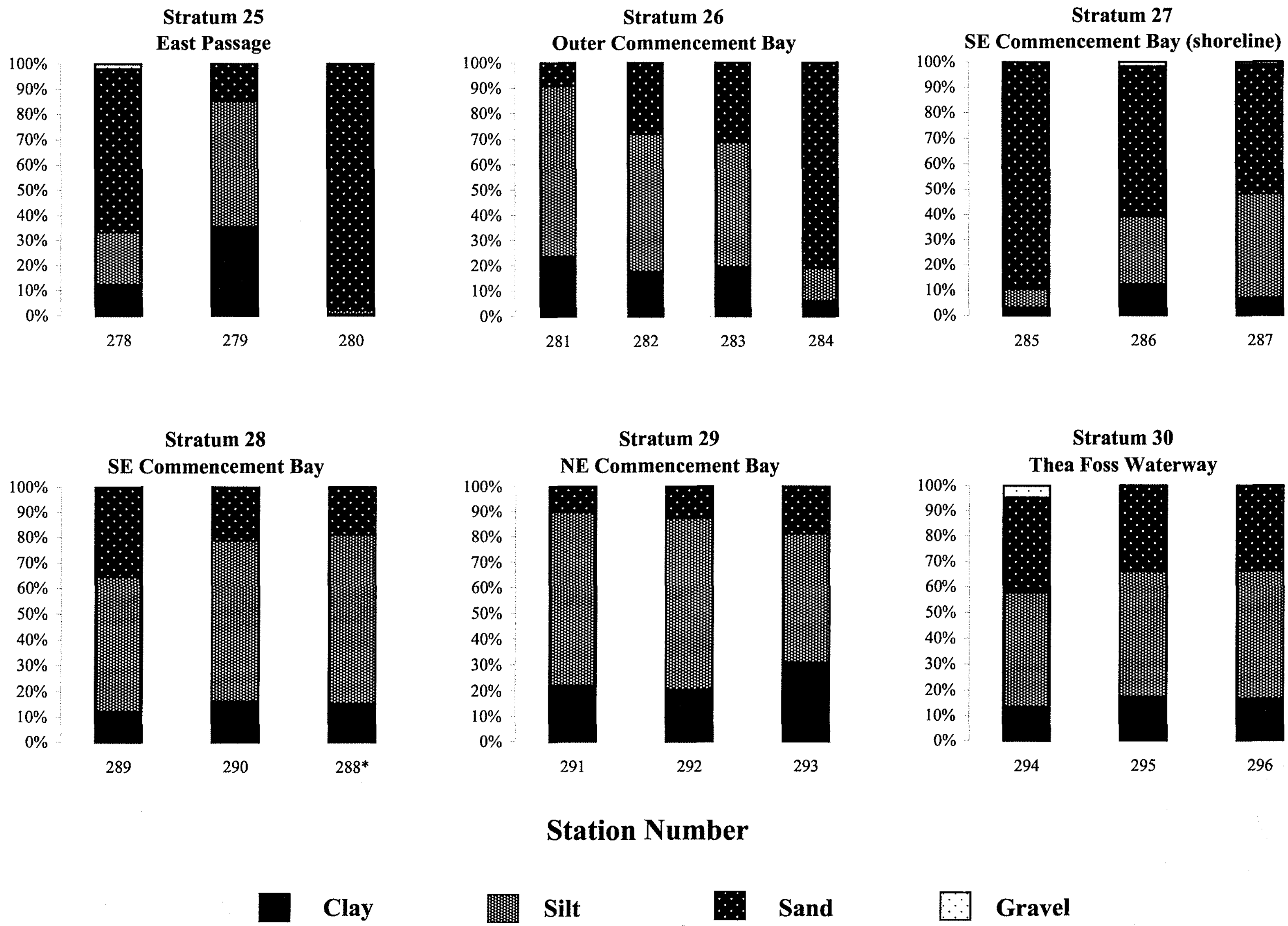
Appendix G, Figure 1. Continued.



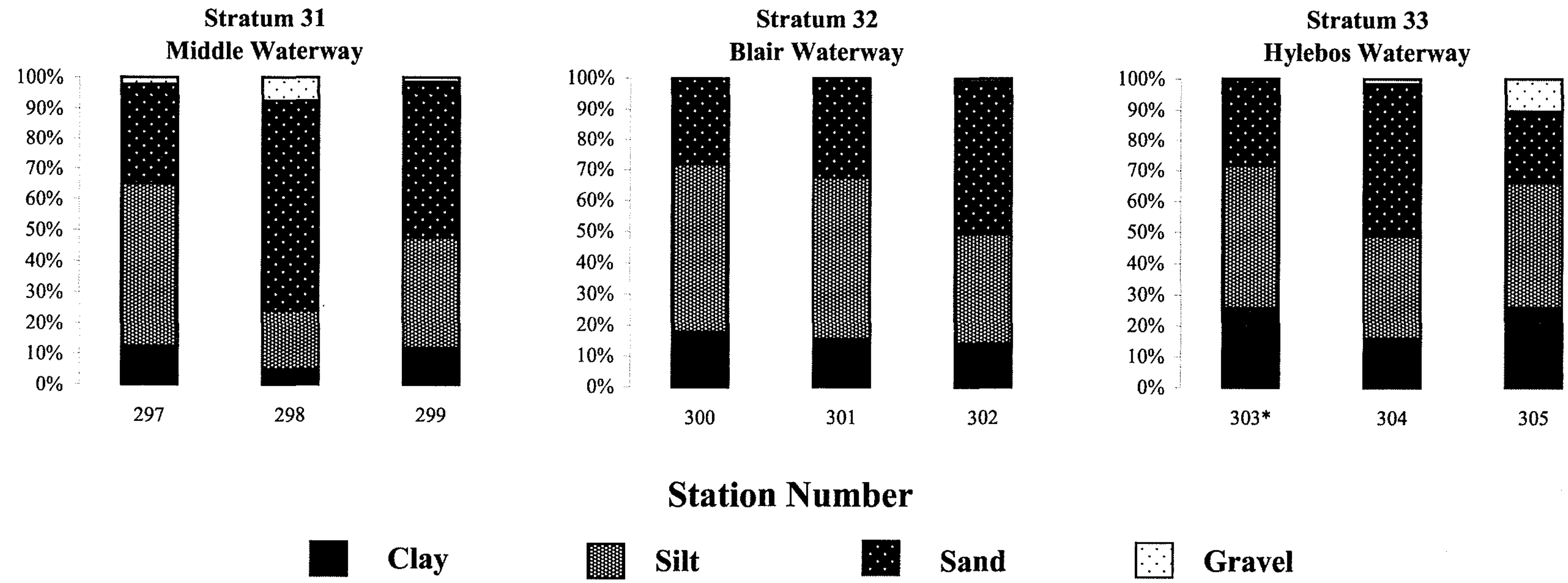
Appendix G, Figure 1. Continued.



Appendix G, Figure 1. Continued.



Appendix G, Figure 1. Concluded.



Appendix H

1999 Southern Puget Sound benthic infaunal species list.

Appendix H. 1999 Southern Puget Sound benthic infaunal species list.

Phylum	Class	Family	Taxon	Authorship
Porifera	Demospongiae		Demospongiae	
Cnidaria	Entozoan		Nynantheae	
		Cerianthidae	Cerianthidae	
			Pachycerianthus fimbriatus	Mcmurrich, 1910
		Edwardsiidae	Edwardsia sipunculoides	(Stimpson, 1853)
		Halcampidae	Halcampa decemtentaculata	Hand, 1954
			Halcampa sp	
			Peachia quinquecapitata	Mcmurrich, 1913
		Metridiidae	Metridium sp	
		Pennatulidae	Ptilosarcus gurneyi	(Gray, 1860)
		Virgulariidae	Acanthoptilum gracile	(Gabb, 1862)
			Stylatula elongata	(Gabb, 1862)
			Virgularia sp	
	Hydrozoa	Aglaopheniidae	Aglaophenia diegensis	Torrey, 1904
		Campanulariidae	Clytia sp	
			Obelia dichotoma	(Linnaeus, 1758)
		Corymorphidae	Euphysa ruthae	Norenburg and Morse, 1983
		Hydromedusae	Hydromedusa	
		Lafoeidae	Lagenicella neosocialis	
		Pandeidae	Pandeidae	
		Plumulariidae	Plumularia setacea	(Linnaeus, 1758)
		Sertulariidae	Abietinaria sp	
			Hydrallmania distans	Nutting, 1899

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
			Selaginopsis triserialis	Mereschkowsky, 1878
			Sertularella sp	
		Tubulariidae	Ectopleura marina	
Ctenophora			Ctenophora	
Platyhelminthes			Polycladida	
	Tubellaria	Stylochidae	Kaburakia excelsa	Bock, 1925
		Leptoplanidae	Leptoplanidae	
Nemertina			Nemertina	
	Anopla	Carinomidae	Carinoma mutabilis	Griffin, 1898
		Lineidae	Cerebratulus sp	
			Lineidae	
			Micrura sp	
		Tubulanidae	Tubulanus cingulatus	(Coe, 1904)
			Tubulanus pellucidus	
			Tubulanus polymorphus	Renier, 1804
			Tubulanus sp	
			Tubulanus sp A	
	Enopla		Hoplonemertea	
			Nipponnemertes pacificus	
		Amphiporidae	Amphiporus sp	
			Zygonemertes virescens	
		Prosorhochmidae	Oerstedia dorsalis	(Abildgaard, 1806)
			Tetrastemma sp	
			Tetrastemma nigrifrons	
Annelida	Hirudinea		Hirudinea	

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
	Oligochaeta		Oligochaeta	
	Polychaeta	Acrocirridae	Macrochaeta pege	
		Ampharetidae	Amage anops	(Johnson, 1901)
			Ampharete acutifrons	(Grube, 1860)
			Ampharete cf crassiseta	
			Ampharete finmarchica	
			Ampharete labrops	Hartman, 1961
			Ampharete sp	
			Ampharetidae	
			Amphicteis scaphobranchiata	Moore, 1906
			Anobothrus gracilis	(Malmgren, 1866)
			Asabellides lineata	(Berkeley & Berkeley, 1943)
			Asabellides sibirica	
			Melinna oculata	Hartman, 1969
			Schistocomus hiltoni	Chamberlin, 1919
		Apistobranchidae	Apistobranchus ornatus	Hartman, 1965
		Capitellidae	Barantolla nr americana	
			Capitella capitata hyperspecies	
			Capitellidae	
			Decamastus gracilis	Hartman, 1963
			Heteromastus filiformis	(Claparède, 1864)
			Heteromastus filobranchus	Berkeley & Berkeley, 1932
			Mediomastus ambiseta	(Hartman, 1947)
			Mediomastus californiensis	Hartman, 1944

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
			Mediomastus sp	
			Notomastus latericeus	M. Sars, 1851
			Notomastus tenuis	Moore, 1909
		Chaetopteridae	Mesochaetopterus sp	
			Mesochaetopterus taylori	
			Phyllochaetopterus claparedii	
			Phyllochaetopterus prolifica	Potts, 1914
			Spiochaetopterus costarum	(Claparède, 1870)
		Chrysopetalidae	Paleanotus bellis	(Johnson, 1897)
		Cirratulidae	Aphelochaeta monilaris	(Hartman, 1960)
			Aphelochaeta sp	
			Aphelochaeta sp N1	
			Aphelochaeta sp N4	
			Caulleriella pacifica	
			Chaetozone acuta	
			Chaetozone nr setosa	
			Chaetozone sp	
			Chaetozone sp N2	
			Cirratulidae	
			Cirratulus robustus	
			Cirratulus sp	
			Cirratulus spectabilis	
			Monticellina sp N1	
		Cossuridae	Cossura bansei	
			Cossura pygodactylata	Jones, 1956
			Cossura sp	

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
		Dorvilleidae	Dorvillea pseudorubrovittata	
			Dorvillea rudolphi	(Delle Chiaje, 1828)
			Parougia caeca	(Webster & Benedict, 1884)
			Protodorvillea gracilis	(Hartman, 1938)
		Flabelligeridae	Brada sachalina	Annenkova, 1922
			Brada villosa	(Rathke, 1843)
			Flabelligera affinis	
			Flabelligeridae	
			Pherusa plumosa	
		Glyceridae	Glycera americana	Leidy, 1855
			Glycera nana	Johnson, 1901
			Glycera sp	
			Glyceridae	
		Goniadidae	Glycinde armigera	Moore, 1911
			Glycinde polygnatha	
			Glycinde sp	
			Goniada brunnea	Treadwell, 1906
			Goniada maculata	Ørsted, 1843
			Goniada sp	
			Goniadidae	
		Hesionidae	Gyptis sp	
			Hesionidae	
			Heteropodarke heteromorpha	Hartmann-Schröder, 1962
			Microphthalmus sczelkowii	

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
			Microphthalmus sp	
			Micropodarke dubia	(Hessle, 1925)
			Podarke pugettensis	Johnson, 1901
			Podarkeopsis glabrus	
		Lumbrineridae	Eranno bicirrata	(Treadwell, 1922)
			Lumbrineridae	
			Lumbrineris californiensis	Hartman, 1944
			Lumbrineris cruzensis	Hartman, 1944
			Lumbrineris limicola	Hartman, 1944
			Lumbrineris sp	
			Ninoe gemmea	
			Scoletoma luti	
		Magelonidae	Magelona longicornis	Johnson, 1901
			Magelona sp	
		Maldanidae	Asychis nr biceps	
			Axiothella rubrocincta	(Johnson, 1901)
			Chirimia similis	
			Clymenura gracilis	Hartman, 1969
			Euclymene cf zonalis	
			Euclymeninae	
			Isocirrus longiceps	(Moore, 1923)
			Maldane glebifex	
			Maldanidae	
			Microclymene caudata	
			Nicomache lumbricalis	(Fabricius, 1780)
			Nicomache personata	Johnson, 1901

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
			Nicomachinae	
			Petaloproctus sp	
			Praxillella gracilis	(M. Sars, 1861)
			Praxillella pacifica	E. Berkeley, 1929
			Praxillella sp	
			Rhodine bitorquata	Moore, 1923
		Nephtyidae	Nephtys caeca	(Fabricius)
			Nephtys caecoides	Hartman, 1938
			Nephtys cornuta	Berkeley & Berkeley, 1945
			Nephtys ferruginea	Hartman, 1940
			Nephtys punctata	Hartman, 1938
			Nephtys sp	
		Nereididae	Neanthes limnicola	
			Nereididae	
			Nereis procera	Ehlers, 1868
			Nereis sp	
			Nereis zonata	
			Platynereis bicanaliculata	(Baird, 1863)
		Oenonidae	Drilonereis falcata	Moore, 1911
			Drilonereis longa	Webster
			Notocirrus californiensis	Hartman, 1944
		Onuphidae	Diopatra ornata	Moore, 1911
			Diopatra sp	
			Onuphidae	
			Onuphis elegans	(Johnson, 1901)

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
			Onuphis geophiliformis	(Moore, 1903)
			Onuphis iridescens	(Johnson, 1901)
			Onuphis sp	
		Opheliidae	Armandia brevis	(Moore, 1906)
			Ophelia limacina	
			Ophelina acuminata	Ørsted, 1843
			Travisia brevis	Moore, 1923
		Orbiniidae	Leitoscoloplos pugettensis	(Pettibone, 1957)
			Leitoscoloplos sp	
			Naineris quadricuspida	(Fabricius)
			Orbiniidae	Hartman, 1942
			Phylo felix	Kinberg, 1866
			Scoloplos acmeceps	Chamberlin, 1919
			Scoloplos armiger	(Muller)
			Scoloplos sp	
		Oweniidae	Galathowenia oculata	
			Myriochele heeri	Malmgren, 1867
			Owenia fusiformis	Delle Chiaje, 1841
		Paraonidae	Aricidea (Acmira) catherinae	Laubier, 1967
			Aricidea (Acmira) lopezi	Berkeley & Berkeley, 1956
			Aricidea (Allia) ramosa	
			Aricidea sp	
			Cirrophorus branchiatus	Ehlers, 1908
			Levinsenia gracilis	(Tauber, 1879)
			Levinsenia oculata	(Hartman, 1957)

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
			Paradoneis lyra	(Southern, 1914)
		Pectinaridae (Amphictenidae)	Pectinaria granulata	
			Pectinaria californiensis	Hartman, 1941
			Pectinaria sp	
		Pholoidae	Pholoides aspera	
		Phyllodocidae	Eteone leptotes	Blake, 1992
			Eteone pacifica	
			Eteone sp	
			Eteone spilotus	
			Eulalia californiensis	(Hartman, 1936)
			Eumida longicornuta	(Moore, 1906)
			Phyllodoce (Anaitides) cuspidata	Mccammon & Montagne, 1979
			Phyllodoce (Anaitides) groenlandica	Oersted
			Phyllodoce (Anaitides) longipes	Kinberg
			Phyllodoce (Aponaitides) hartmanae	
			Phyllodoce sp	
			Pterocirrus montereyensis	(Hartman, 1936)
		Pilargidae	Parandalia fauveli	(Berkeley & Berkeley, 1941)
			Pilargis maculata	
			Sigambra bassi	(Hartman)
		Polynoidae	Gattyana ciliata	Moore, 1902
			Gattyana cirrosa	(Malmgren, 1865)

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
			Gattyana treadwelli	Pettibone, 1949
			Grubeopolynoe tuta	(Grube, 1855)
			Harmothoe imbricata	(Linnaeus, 1767)
			Harmothoe sp	
			Harmothoinae	
			Hesperonoe laevis	Hartman, 1961
			Lepidasthenia berkeleyae	Pettibone, 1948
			Lepidonotus squamatus	(Linnaeus, 1767)
			Malmgreniella bansei	Pettibone, 1993
			Malmgreniella liei	Pettibone, 1993
			Malmgreniella sp	
			Polynoidae	Malmgren, 1867
			Tenonia priops	(Hartman, 1961)
		Sabellariidae	Idanthyrsus saxicavus	
			Neosabellaria cementarium	(Moore, 1906)
		Sabellidae	Chone duneri	
			Chone magna	
			Chone sp	
			Demonax rugosus	(Moore, 1904)
			Demonax sp	
			Euchone incolor	Hartman, 1965
			Euchone limnicola	Reish, 1960
			Eudistylia catherinae	
			Eudistylia sp	
			Laonome kroeyeri	Malmgren, 1866
			Manayunkia aestuarina	

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
			Megalomma splendida	(Moore, 1905)
			Myxicola infundibulum	(Renier)
			Potamilla sp	
			Sabellidae	Malmgren, 1867
		Scalibregmidae	Asclerocheilus beringianus	
			Scalibregma inflatum	Rathke, 1843
		Sigalionidae	Pholoe minuta	(Fabricius)
			Pholoe sp	
			Pholoe sp N1	
			Sthenelais berkeleyi	Pettibone, 1971
			Sthenelais fusca	Johnson, 1897
			Sthenelais tertiaglabra	Moore, 1910
		Sphaerodoridae	Sphaerodoropsis sphaerulifer	(Moore, 1909)
			Sphaerodorum papillifer	Moore, 1909
		Spionidae	Boccardia pugettensis	Blake, 1979
			Boccardiella hamata	(Webster, 1879)
			Boccardiella sp	
			Dipolydora cardalia	
			Dipolydora caulleryi	(Mesnil, 1897)
			Dipolydora socialis	(Schmarda, 1861)
			Laonice cirrata	(M. Sars, 1851)
			Laonice pugettensis	
			Laonice sp	
			Paraprionospio pinnata	(Ehlers, 1901)
			Polydora cornuta	Bosc, 1802
			Polydora limicola	Annenkova, 1934

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
			Polydora sp	
			Prionospio (Minuspio) lighti	Maciolek, 1985
			Prionospio (Minuspio) multibranchiata	E. Berkeley, 1927
			Prionospio jubata	
			Prionospio sp	
			Prionospio steenstrupi	Malmgren
			Pseudopolydora kempi	
			Pygospio elegans	
			Rhynchospio glutaea	
			Spio filicornis	(O. F. Müller, 1766)
			Spionidae	
			Spiophanes berkeleyorum	Pettibone, 1962
			Spiophanes bombyx	(Claparède, 1870)
			Spiophanes sp	
			Streblospio benedicti	Webster, 1879
		Sternaspidae	Sternaspis scutata	
		Syllidae	Autolytus verrilli	
			Eusyllis blomstrandi	
			Eusyllis habei	Imajima, 1966
			Exogone dwisula	Kudenov & Harris, 1995
			Exogone lourei	
			Exogone molesta	
			Exogone sp	
			Odontosyllis phosphorea	Moore, 1909

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
			Pionosyllis sp	
			Proceraea cornuta	
			Sphaerosyllis californiensis	Hartman, 1966
			Sphaerosyllis ranunculus	Kudenov & Harris, 1995
			Sphaerosyllis sp N1	
			Syllidae	
			Syllis (Ehlersia) heterochaeta	Moore, 1909
			Syllis (Ehlersia) hyperioni	Dorsey & Phillips, 1987
			Syllis (Typosyllis) harti	
		Terebellidae	Amphitrite edwardsi	
			Amphitrite robusta	Johnson, 1901
			Amphitrite sp	
			Artacama coniferi	Moore, 1905
			Lanassa nordenskioldi	
			Lanassa sp	
			Lanassa venusta	
			Pista bansei	
			Pista brevibranchiata	
			Pista elongata	Moore, 1909
			Pista sp	
			Pista wui	
			Polycirrinae	
			Polycirrus californicus	Moore, 1909
			Polycirrus sp	
			Polycirrus sp I sensu Banse	

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
			1980	
			Polycirrus sp III sensu Banse 1980	
			Polycirrus sp V sensu Banse 1980	
			Proclea graffii	
			Scionella japonica	Moore, 1903
			Streblosoma bairdi	(Malmgren, 1866)
			Streblosoma sp	
			Terebellidae	
		Trichobranchidae	Terebellides californica	Williams, 1984
			Terebellides reishi	Williams, 1984
			Terebellides sp	
		Trochochaetidae	Trochochaeta multisetosa	(Ørsted, 1844)
		Capitellidae	Notomastus lineatus	Claparède, 1870
Mollusca	Gastropoda		Gastropoda	Cuvier, 1797
			Nudibranchia	Cuvier, 1817
			Olea hansineensis	Agersborg, 1923
			Scaphandridae	
		Acteonidae	Rictaxis punctocaelatus	(Carpenter, 1864)
		Aglajidae	Aglaja ocelligera	(Bergh, 1893)
		Aglajidae	Melanochlamys diomedea	(Bergh, 1893)
		Atyidae	Haminoea vesicula	Gray, 1840
		Calyptraeidae	Crepipatella dorsata	(Broderip, 1834)
		Cephalaspidea	Cephalaspidea	P. Fischer, 1883
		Cerithiidae	Lirobittium sp	

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
		Columbellidae	Alia carinata	(Hinds, 1844)
			Astyris gausapata	
		Corambidae	Corambe pacifica	Macfarland and O'donoghue, 1929
			Doridella steinbergae	(Lance, 1962)
		Cylichnidae	Acteocina culcitella	(Gould, 1853)
			Acteocina harpa	(Dall, 1871)
			Cylichna attonsa	Carpenter, 1865
			Scaphander sp	
		Diaphanidae	Diaphana sp	
		Epitoniidae	Epitonium sawinae	(Dall, 1903)
		Eulimidae	Balcis sp	
		Flabellinidae	Flabellina sp	
		Gastropteridae	Gastropteron pacificum	Bergh, 1893
		Lacunidae	Lacuna sp	
			Lacuna vincta	(Montagu, 1803)
		Littorinidae	Littorina sp	
		Nassariidae	Nassarius mendicus	(Gould, 1849)
		Naticidae	Cryptonatica affinis	
			Euspira pallida	
			Euspira sp	
		Olividae	Olivella baetica	Carpenter, 1864
		Philinidae	Philine sp	
		Pyramidellidae	Cyclostremella concordia	
			Odostomia sp	
			Turbonilla sp	

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
		Rissoidae	Alvania compacta	Carpenter, 1864
			Alvania sp 1	
		Skeneopsidae	Skeneopsis alaskana	Dall, 1919
		Trichotropididae	Trichotropis cancellata	Hinds, 1843
		Tritoniidae	Tritonia cf diomedea	Bergh, 1894
		Trochidae	Lirularia lirulata	
			Margarites pupillus	(Gould, 1849)
		Turridae	Kurtzia arteaga	(Dall & Bartsch, 1910)
			Kurtziella crebricostata	
	Polyplacophora	Lepidopleuridae	Leptochiton cf nexus	Carpenter, 1864
			Leptochiton rugatus	
	Aplacophora	Chaetodermatidae	Chaetoderma sp	
	Bivalvia		Bivalvia	Linnaeus, 1758
		Cardiidae	Clinocardium blandum	(Gould, 1850)
			Clinocardium nuttallii	(Conrad, 1837)
			Clinocardium sp	
			Nemocardium centifilosum	(Carpenter, 1864)
		Hiatellidae	Hiatella arctica	(Linnaeus, 1767)
			Panomya ampla	Dall, 1894
			Saxicavella pacifica	Dall, 1916
		Lasaeidae	Rochefortia cf coani	
		Lucinidae	Lucinoma annulatum	(Reeve, 1850)
			Parvilucina tenuisculpta	(Carpenter, 1864)
		Lyonsiidae	Lyonsia californica	Conrad, 1837
		Mactridae	Mactromeris polynyma	(Stimpson, 1860)

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
		Montacutidae	Kellia suborbicularis	(Montagu, 1803)
			Rochefortia tumida	
		Myidae	Cryptomya californica	(Conrad, 1837)
			Mya arenaria	Linnaeus, 1758
		Mytilidae	Modiolus rectus	(Conrad, 1837)
			Modiolus sp	
			Musculus discors	(Linnaeus, 1767)
			Mytilidae	
			Mytilus sp	
			Solamen columbiana	
		Nuculanidae	Ennucula tenuis	
		Nuculidae	Acila castrensis	(Hinds, 1843)
		Pandoridae	Pandora filosa	(Carpenter, 1864)
		Sareptidae	Yoldia hyperborea	Torell, 1859
			Yoldia seminuda	Dall, 1871
			Yoldia sp	
			Yoldia thraciaeformis	(Storer, 1838)
		Semelidae	Semele rubropicta	Dall, 1871
		Solenidae	Solen sicarius	Gould, 1850
		Tellinidae	Macoma carlottensis	Whiteaves, 1880
			Macoma elimata	Dunnill & Coon, 1968
			Macoma inquinata	(Deshayes, 1855)
			Macoma moesta	(Deshayes, 1855)
			Macoma nasuta	(Conrad, 1837)
			Macoma obliqua	(Sowerby, 1817)

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
			Macoma sp	
			Macoma yoldiformis	Carpenter, 1864
			Tellina modesta	(Carpenter, 1864)
			Tellina nuculoides	(Reeve, 1854)
			Tellina sp	
		Teredinidae	Bankia setacea	(Tryon, 1863)
		Thyasiridae	Adontorhina cyclia	Berry, 1947
			Adontorhina sphaericosa	Scott, 1986
			Axinopsida serricata	(Carpenter, 1864)
			Thyasira flexuosa	(Montagu, 1803)
		Veneridae	Compsomyax subdiaphana	(Carpenter, 1864)
			Nutricola lordi	(Baird, 1863)
			Protothaca staminea	(Conrad, 1837)
			Saxidomus giganteus	(Deshayes, 1839)
	Scaphopoda	Pulsellidae	Pulsellum salishorum	E. Marshall, 1980
Arthropoda	Pycnogonida	Nymphonidae	Nymphon sp	
		Phoxichilidiidae	Phoxichilidium femoratum	
	Cirripedia	Balanidae	Balanus sp	
	Copepoda		Calanoida	Mauchline, 1988
			Calanus pacificus	Brodsky, 1948
			Cyclopoida	
			Harpacticoida	
	Malacostraca		Euphausia pacifica	Hansen, 1911
			Euphausia sp	
			Euphausiacea furcilia	
			Mysidacea	

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
			Pacifoculodes sp	
			Pacifoculodes zernovi	
		Aeginellidae	Tritella pilimana	Mayer, 1890
		Alpheidae	Eualus cf pusiolus	
			Eualus stimpsoni	
		Ampeliscidae	Ampelisca cristata	Holmes, 1908
			Ampelisca hancocki	J. L. Barnard, 1954
			Ampelisca lobata	Holmes, 1908
			Ampelisca macrocephala	Liljeborg
			Ampelisca pacifica	Holmes, 1908
			Ampelisca sp	
			Ampelisca unsocalae	J. L. Barnard, 1960
			Byblis millsi	Dickinson, 1983
		Ampithoidae	Ampithoe lacertosa	Bate, 1858
		Anthuridae	Silophasma geminata	
		Aoridae	Aoroides columbiae	Walker, 1898
			Aoroides inermis	Conlan & Bousfield, 1982
			Aoroides intermedius	Conlan and Bousfield, 1982
			Aoroides sp	
			Aoroides spinosus	Conlan and Bousfield, 1982
		Argissidae	Argissa hamatipes	(Norman, 1869)
		Axiidae	Acanthaxius (Axiopsis) spinulicauda	
			Axiidae	Huxley, 1879

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
			Axiopsis spinulicauda	(Rathbun, 1902)
		Bopyridae	cf Hemiarthrus abdominalis	(Kroyer, 1840)
		Callianassidae	Neotrypaea californiensis	(Dana, 1854)
			Neotrypaea sp	
		Cancridae	Cancer gracilis	Dana, 1852
		Caprellidae	Caprella laeviuscula	
			Caprella mendax	Mayer, 1903
			Caprella sp	
			Metacaprella anomala	
			Metacaprella kennerlyi	(Stimpson, 1864)
		Corophiidae	Corophiidae	
			Corophium (Laticorophium) baconi	
			Corophium (Monocorophium) acherusicum	
		Crangonidae	Crangon alaskensis	Lockington, 1877
			Crangonidae	Haworth, 1825
			Mesocrangon munitella	(Walker, 1898)
		Dexaminidae	Guernea reduncans	(J. L. Barnard, 1958)
		Diastylidae	Diastylis bidentata	
			Diastylis pellucida	Hart, 1930
			Diastylis santamariensis	Watling & Mccann, 1997
			Diastylis sentosa	
			Diastylis sp	
			Leptostylis cf villosa	
			Leptostylis sp	

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
		Eusiridae	Eusirus columbianus	
			Rhachotropis barnardi	
			Rhachotropis sp	
		Grapsidae	Hemigrapsus oregonensis	(Dana, 1851)
		Hippolytidae	Hippolytidae	Bate, 1888
		Hyperiidae	Hyperiidae	
		Isaeidae	Gammaropsis thompsoni	(Walker, 1898)
			Photis brevipes	Shoemaker, 1942
			Photis parvidons	Conlan, 1983
			Photis sp	
			Protomedeia prudens	J. L. Barnard, 1966
		Ischyroceridae	Ischyrocerus anguipes group	
			Ischyrocerus sp	
		Lampropidae	Lamprops sp	
		Leuconiidae	Eudorella pacifica	Hart, 1930
			Eudorellopsis integra	
			Eudorellopsis longirostris	Given, 1961
			Leucon subnasica	Given, 1961
		Limnoriidae	Limnoria lignorum	(Rathke, 1799)
		Lysianassidae	Anonyx cf lilljeborgi	
			Hippomedon sp	
			Lepidepecreum gurjanovae	Hurley, 1963
			Orchomene decipiens	(Hurley, 1963)
			Orchomene obtusa	Sars, 1895
			Orchomene sp	

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
			Pachynus barnardi	Hurley, 1963
			Pachynus cf barnardi	Hurley, 1963
		Melitidae	Anisogammarus pugettensis	Dana, 1853
			Desdimelita desdichada	(J. L. Barnard, 1962)
		Munnidae	Munna ubiquita	Menzies, 1952
		Mysidae	Pseudomma berkeleyi	W. Tattersall, 1932
			Pseudomma sp	
		Nannastacidae	Campylaspis canaliculata	Zimmer, 1936
			Campylaspis rubromaculata	Lie, 1971
		Nebaliidae	Nebalia cf pugettensis	
		Oedicerotidae	Americhelidium shoemakeri	
			Bathymedon pumilus	J. L. Barnard, 1962
			Bathymedon sp	
			Deflexilodes sp	
			Westwoodilla caecula	Bate, 1856
		Paguridae	Paguridae	Latreille, 1803
		Paguridae	Pagurus armatus	(Dana, 1851)
		Pandalidae	Pandalus tridens	Rathbun, 1902
		Paratanaidae	Leptochelia dubia	(Krøyer, 1842)
		Phoxocephalidae	Eyakia robustus	(Holmes, 1908)
			Heterophoxus affinis	(Holmes, 1908)
			Paraphoxus cf gracilis	
			Paraphoxus sp	
			Rhepoxynius barnardi	

Phylum	Class	Family	Taxon	Authorship
			Rhepoxynius boreovariatus	
		Pinnotheridae	Pinnixa occidentalis	Rathbun, 1893
			Pinnixa sp	
			Pinnotheridae	
			Scleroplax granulata	Rathbun, 1893
		Pleustidae	Parapleustinae	
		Podoceridae	Dulichia sp	
			Dyopedos arcticus	Murdoch, 1885
			Dyopedos sp	
		Pontogeneiidae	Accedomoera vagor	J. L. Barnard, 1969
		Stenothoidae	Metopa cf dawsoni	
			Stenothoidae	Chevreux
			Stenothoides sp	Chevreux, 1900
		Synopiidae	Tiron sp	
		Tanaidae	Zeuxo normani	(Richardson, 1905)
		Upogebiidae	Upogebiidae	Borradaile, 1903
	Ostracoda	Cylindroleberididae	Bathyleberis sp	
		Philomedidae	Euphilomedes carcharodonta	(Smith, 1952)
			Euphilomedes producta	Poulsen, 1962
			Euphilomedes sp	
		Rutidermatidae	Rutiderma cf lomae	
	Insecta	Tipulinae	Ctenophora	Meigen, 1803
Sipuncula			Sipuncula	
	Sipunculidea	Golfingiidae	Thysanocardia nigra	(Ikeda, 1904)
			Thysanocardia sp	

Appendix H. Continued.

Phylum	Class	Family	Taxon	Authorship
Echiura	Echiurida	Bonelliidae	Bonelliidae	
		Echiridae	Echiurus echiurus alaskanus	
Priapulida		Priapulidae	Priapulus caudatus	
Phoronida			Phoronida	
Phorona		Phoronidae	Phoronis sp	
Phorona			Phoronopsis harmeri	
Bryozoa	Gymnolaemata	Alcyonidiidae	Alcyonidium sp	
		Hippothoidae	Celleporella hyalina	(Linnaeus, 1767)
		Vesiculariidae	Bowerbankia gracilis	Leidy, 1855
Entoprocta		Barentsiidae	Barentsia benedeni	(Foettinger, 1887)
			Barentsia gracilis	
		Pedicellinidae	Myosoma spinosa	
Brachiopoda	Articulata	Laqueidae	Terebratalia transversa	(G. B. Sowerby I., 1846)
Echinodermata	Asteroidea		Asteroidea	
		Solasteridae	Crossaster papposus	(Linnaeus, 1767)
	Echinoidea	Schizasteridae	Brisaster latifrons	(A. Agassiz, 1898)
	Holothuroidea		Dendrochirotida	Brandt, 1835
		Cucumariidae	Cucumaria sp	
			Thyone benti	Deichmann, 1937
		Mopadiidae	Molpadia intermedia	(Ludwig, 1894)
		Phyllophoridae	Pentamera lissoplaca	(H. L. Clark, 1924)
			Pentamera populifera	(Stimpson, 1857)
			Pentamera sp	
			Phyllophoridae	Oestergren, 1907

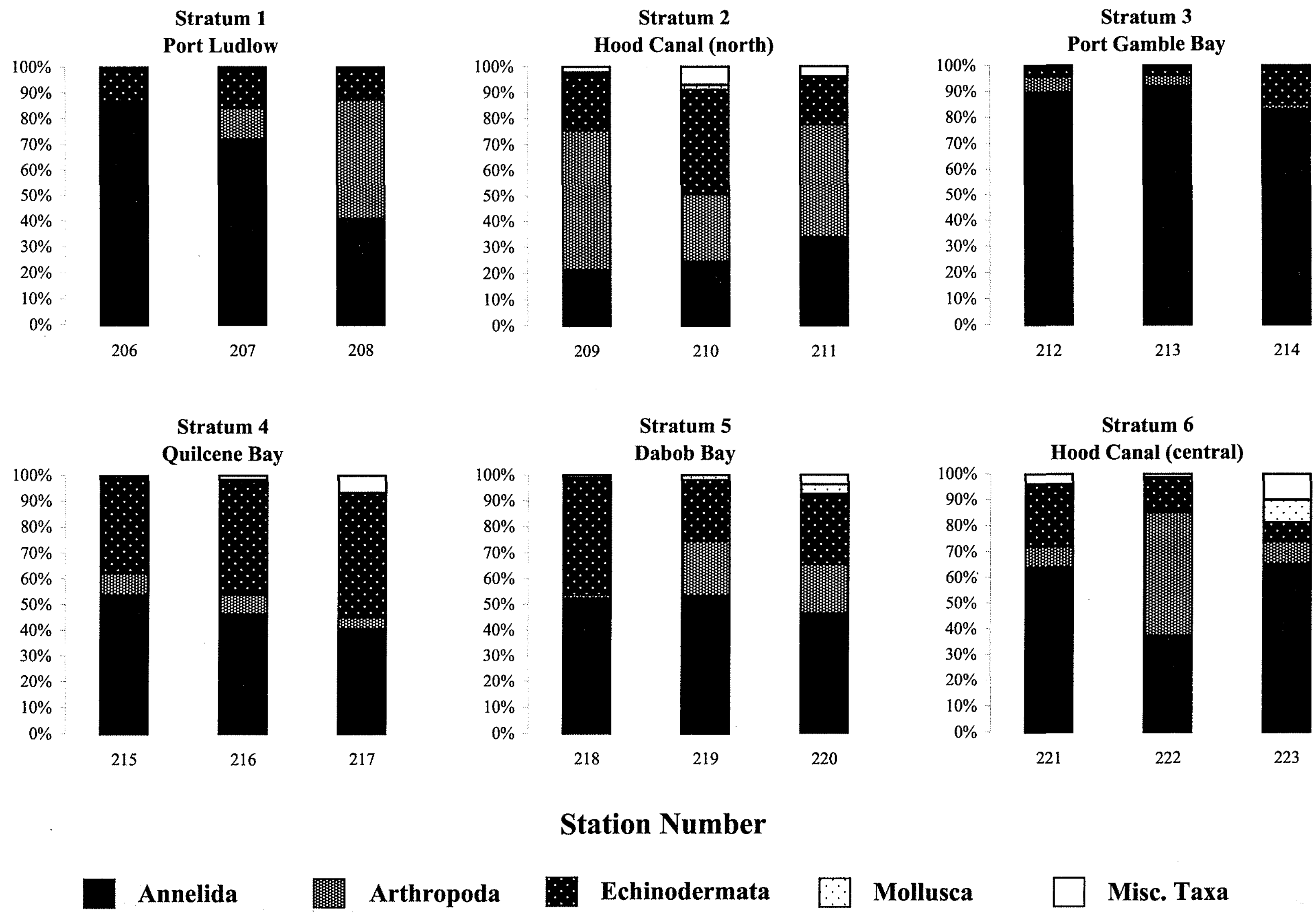
Appendix H. Concluded.

Phylum	Class	Family	Taxon	Authorship
		Stichopodidae	Parastichopus californicus	(Stimpson, 1857)
		Synaptidae	Leptosynapta transgressor	Heding, 1928
	Ophiuroidea		Ophiurida	Muller & Troschel, 1940
		Amphiuridae	Amphiodia (Amphispina) urtica/periercta	
			Amphiodia sp	
			Amphipholis squamata	(Delle Chiaje, 1828)
			Amphiuridae	Ljungman, 1867
		Ophiuridae	Ophiura lütkeni	(Lyman, 1860)
Hemichordata	Enteropneusta		Enteropneusta	
Chaetognatha			Chaetognatha	
	Sagittoidea	Sagittidae	Sagitta sp	
Chordata	Ascidiacea	Molgulidae	Molgula pugettensis	Herdman, 1898
		Styelidae	Styela gibbsii	(Stimpson, 1864)
			Styela sp	

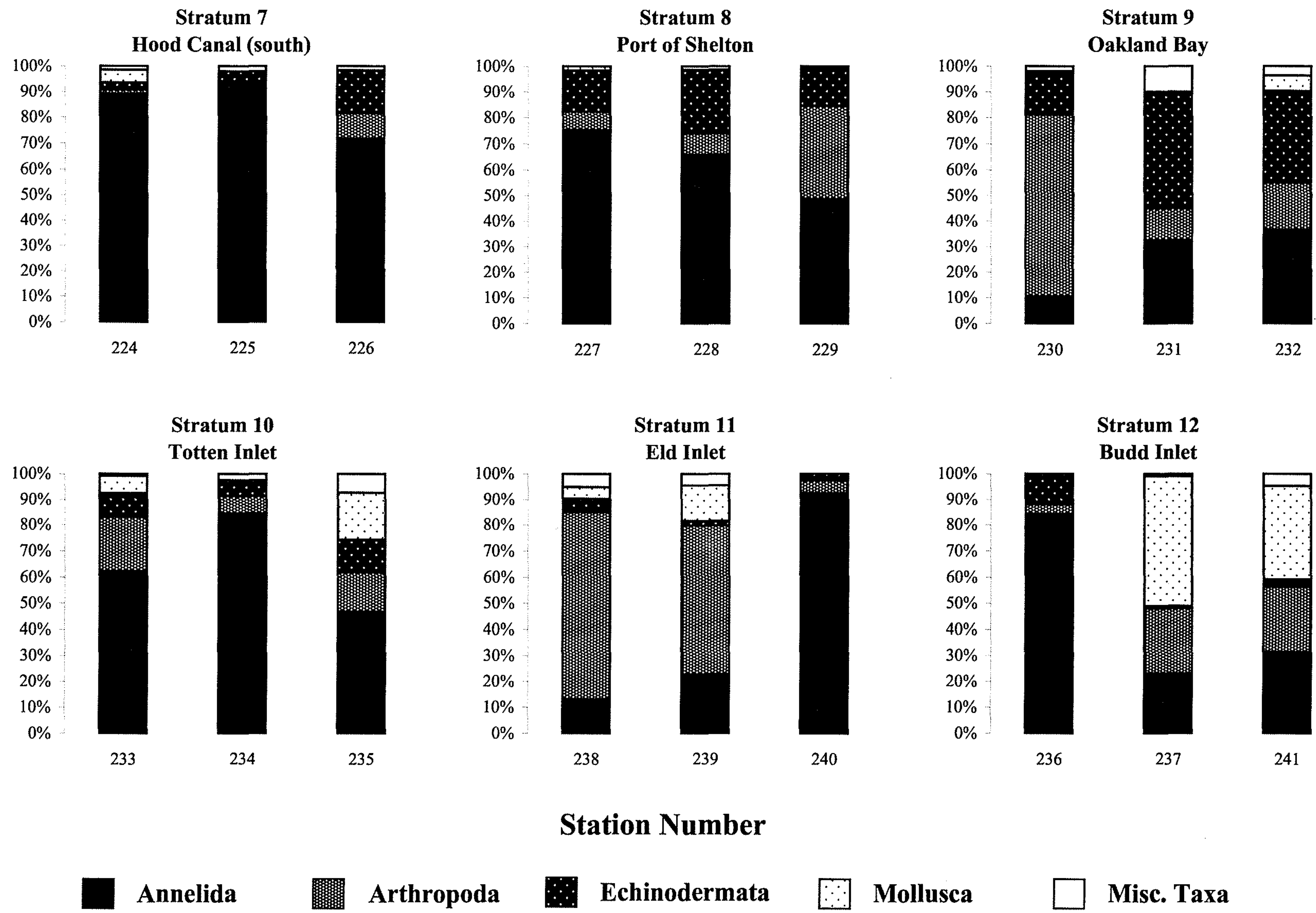
Appendix I

Percent taxa abundance for the 1999 southern Puget Sound sampling stations.

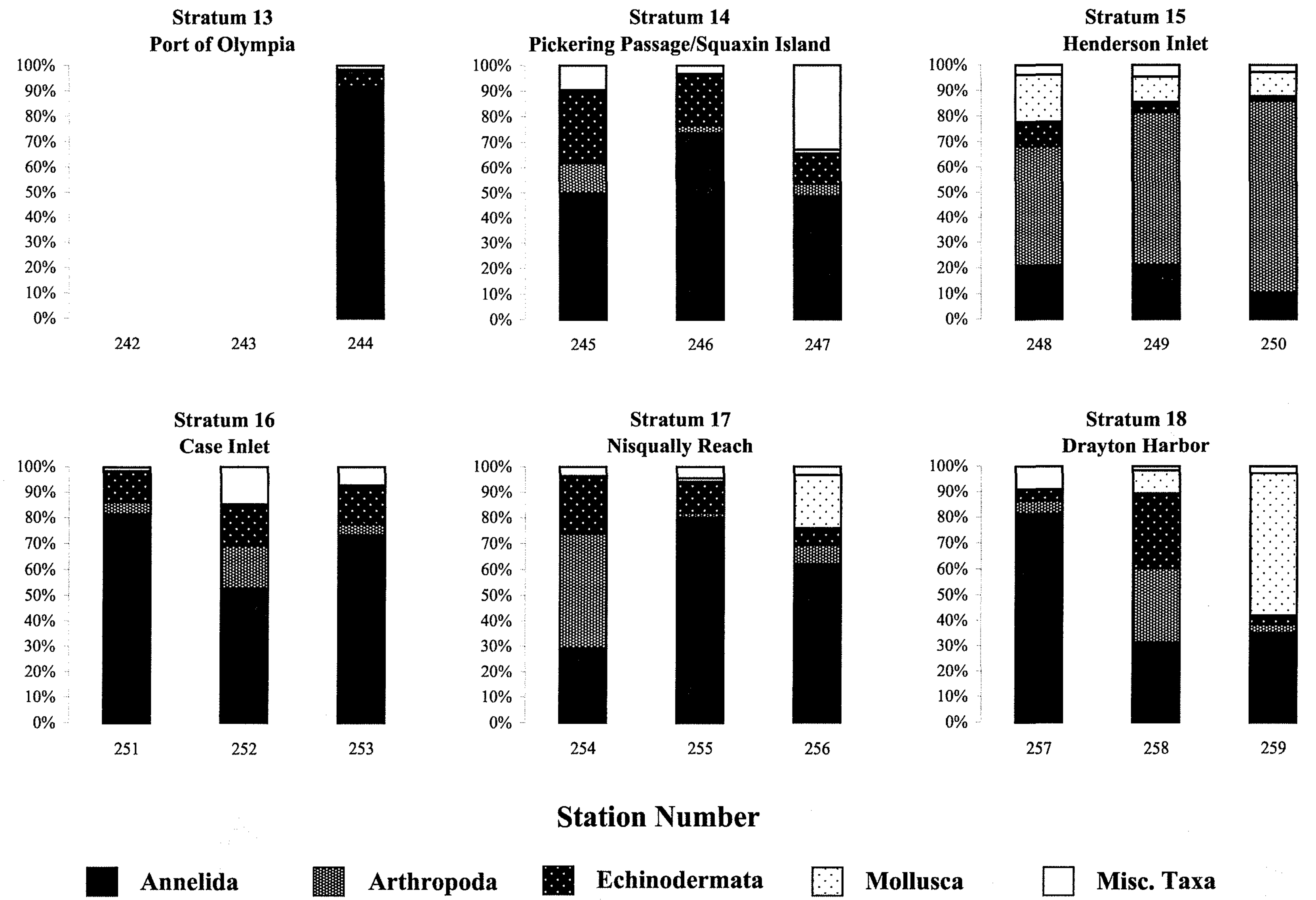
Appendix I. Percent taxa abundance for the 1999 southern Puget Sound sampling stations.



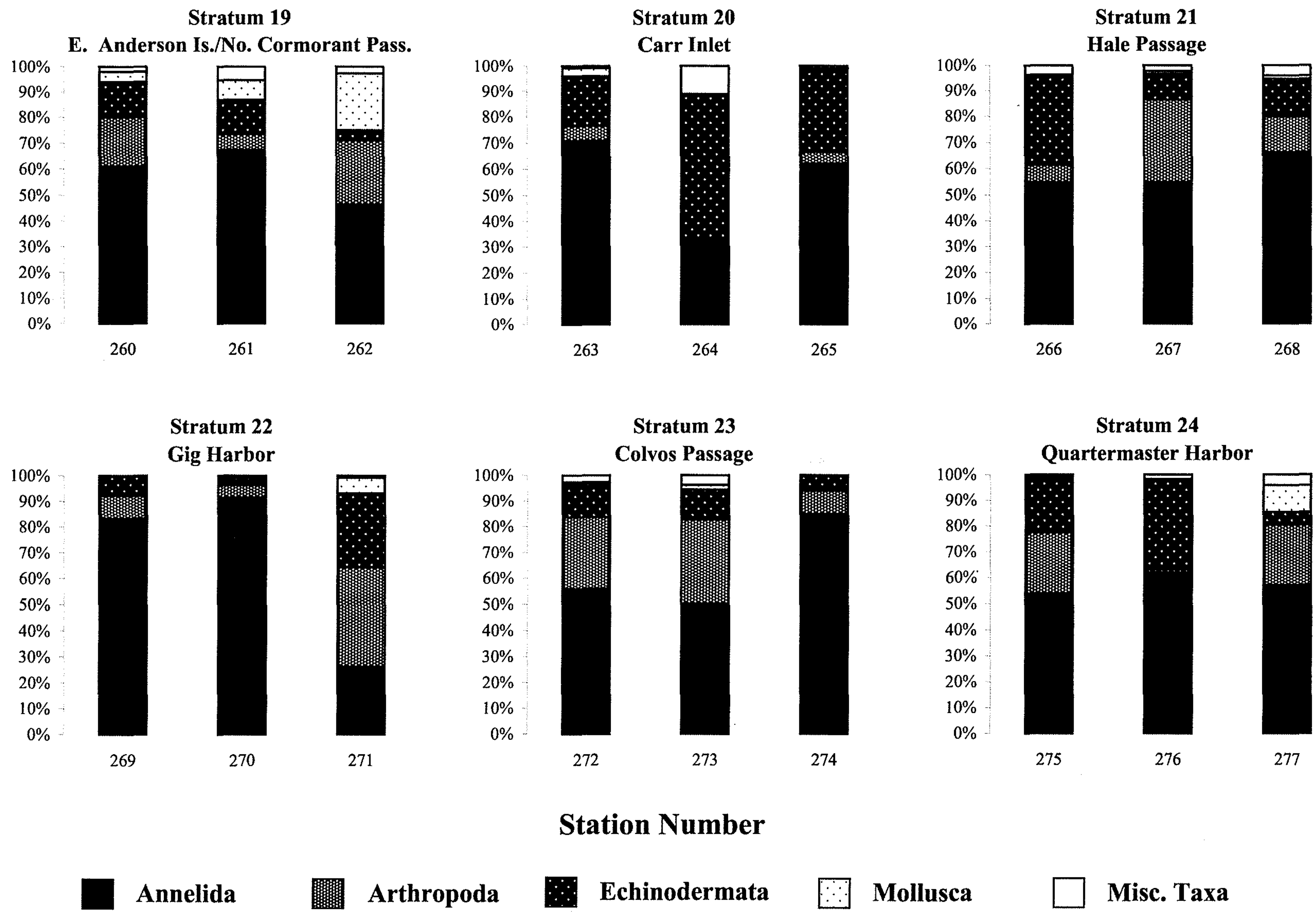
Appendix I. Continued.



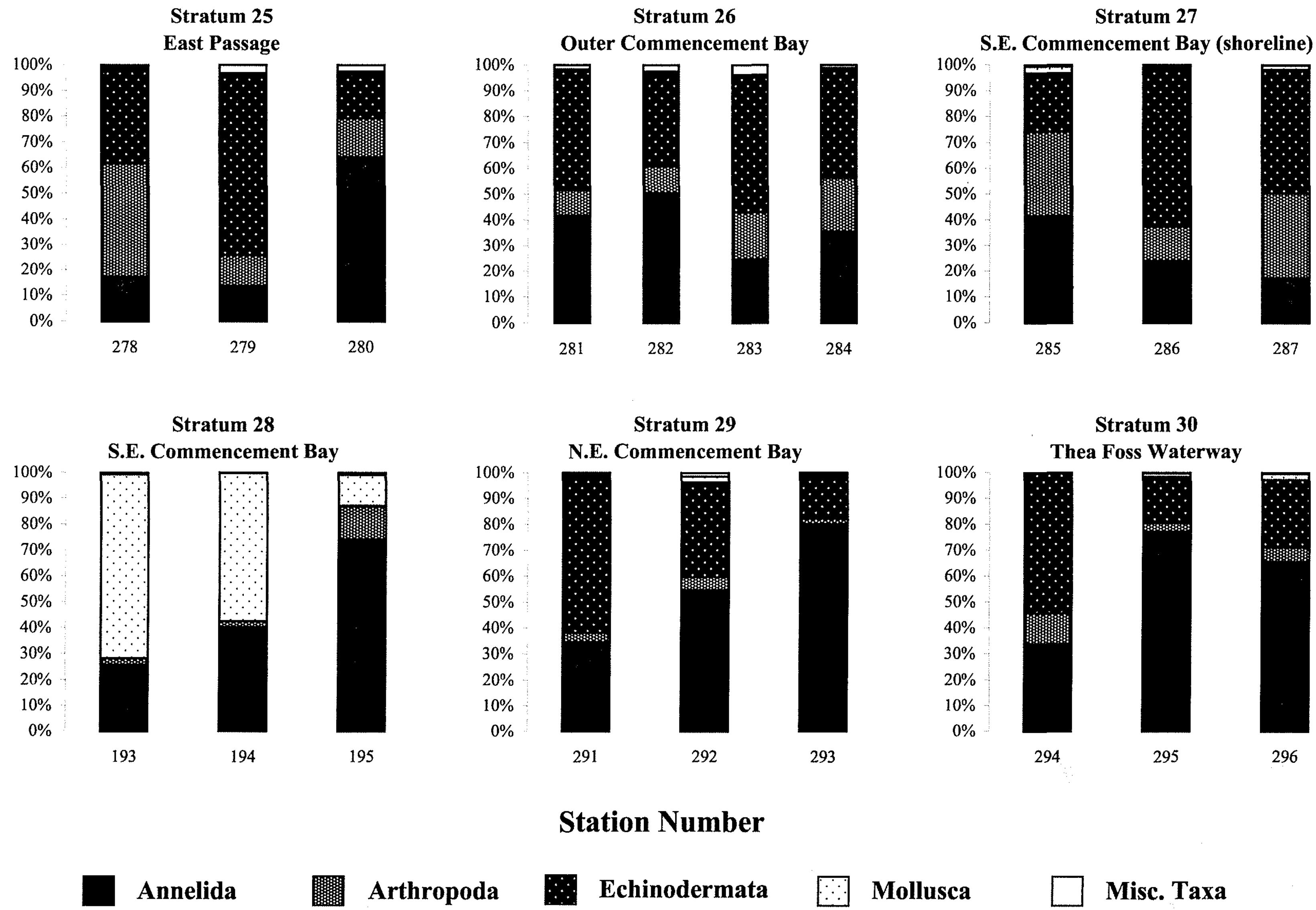
Appendix I. Continued.



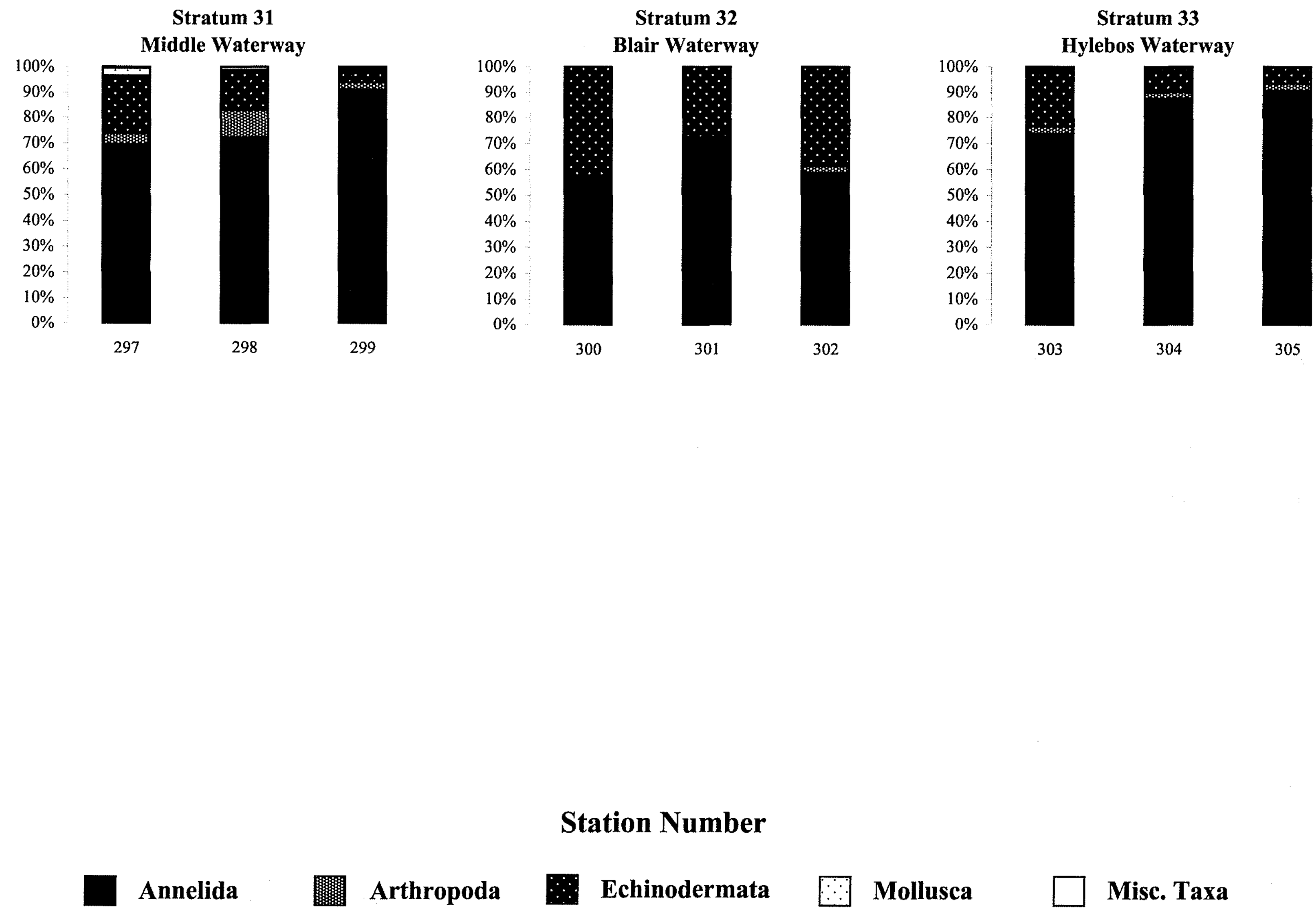
Appendix I. Continued.



Appendix I. Continued.



Appendix I. Concluded.



Appendix J

Triad data - Results of selected toxicity, chemistry, and infaunal analysis for all 1999 southern Puget Sound stations.

Appendix J. Triad results of selected, toxicity, chemistry, and infaunal analysis for all 1999 southern Puget Sound stations.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
1, 206, Port Ludlow	1.6	9	0.2				103.0		106.8		1.0		102.9	+++	688	32	0.5	2	595	1	0	90	2	Aphelochaeta sp	321	yes
																								Aphelochaeta sp N1	235	
																								Axinopsida serricata	33	
																								Acila castrensis	14	
1, 207, Port Ludlow	1.6	5	0.1		LPAHs: Naphthalene		97.0		106.6		6.9		4.4		953	58	0.6	6	687	115	0	148	3	Aphelochaeta sp	293	yes
																								Aphelochaeta sp N1	260	
																								Euphilomedes carcharodonta	65	
																								Nutricola lordi	47	
1, 208, Port Ludlow	1.6	5	0.1				93.3		81.8	*	2.0		6.0		1574	47	0.6	6	645	731	0	198	0	Aoroides spinosus	411	no
																								Oligochaeta	350	
																								Leptochelia dubia	195	
																								Aoroides sp	103	
2, 209, Hood Canal (north)	35.7	0	0.1				106.7		105.5		7.4		6.7		408	68	0.6	14	87	221	4	87	9	Euphilomedes producta	184	no
																								Macoma carlottensis	24	
																								Pinnixa sp	16	
																								Macoma elimata	13	
2, 210, Hood Canal (north)	35.7	0	0.1				108.6		106.1		8.6		6.7		517	84	0.8	19	127	134	10	210	36	Axinopsida serricata	68	no
																								Euphilomedes producta	68	
																								Nutricola lordi	52	
																								Leitoscoloplos pugettensis	36	
2, 211, Hood Canal (north)	35.7	1	0.1				103.7		105.7		7.3		5.1		587	92	0.8	22	198	257	2	107	23	Photis parvidons	88	no
																								Photis sp	86	
																								Spiophanes bombyx	36	
																								Astyris gausapata	19	
3, 212, Port Gamble Bay	1.4	6	0.1	Metals: Silver			100.0		105.9		2.2		15.0	++	1966	82	0.4	2	1764	119	7	69	7	Aphelochaeta sp N1	1271	yes
																								Cirratulidae	206	
																								Euphilomedes carcharodonta	74	
																								Scoletoma luti	55	

Appendix J. Continued.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
3, 213, Port Gamble Bay	1.4	3	0.1				98.0		107.0		1.7		8.2		3476	85	0.3	2	3202	143	10	107	14	Aphelochaeta sp N1	2556	yes
																								Cirratulidae	132	
																								Maldanidae	96	
																								Owenia fusiformis	74	
3, 214, Port Gamble Bay	1.4	18	0.5	LPAHs: Acenaphthylene, Naphthalene, Phenanthrene, Total LPAH			102.3		71.5	**	1.0		36.8	++	939	59	0.5	6	781	16	4	138	0	Aphelochaeta sp N1	546	yes
																								Dipolydora socialis	46	
																								Odostomia sp	45	
																								Paraprionospio pinnata	38	
4, 215, Quilcene Bay	0.9	3	0.2				100.0		101.2		4.4		5.3		753	46	0.8	13	405	64	7	269	8	Trochochaeta multisetosa	127	no
																								Parvilucina tenuisculpta	85	
																								Heteromastus filobranchus	71	
																								Axinopsida serricata	45	
4, 216, Quilcene Bay	0.9	2	0.1				96.6		104.4		19.6		3.6		744	70	0.8	16	344	56	6	325	13	Trochochaeta multisetosa	97	no
																								Macoma sp	89	
																								Macoma carlottensis	60	
																								Pectinaria californiensis	43	
4, 217, Quilcene Bay	0.9	2	0.1				103.0		105.9		45.2		4.6		892	81	0.8	15	361	41	2	427	61	Axinopsida serricata	123	no
																								Macoma sp	109	
																								Trochochaeta multisetosa	102	
																								Macoma carlottensis	65	
5, 218, Dabob Bay	18.6	2	0.1				98.0		105.7		29.8		3.6		281	43	0.7	11	147	4	0	127	3	Pectinaria californiensis	61	no
																								Axinopsida serricata	48	
																								Macoma carlottensis	45	
																								Levinsenia gracilis	21	

Appendix J. Continued.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
5, 219, Dabob Bay	18.6	3	0.1				100.0		40.9	**	21.4		14.5	++	47	20	0.9	10	25	10	1	11	0	Macoma carlottensis	9	no
																								Nephtys cornuta	5	
																								Leitoscoloplos pugettensis	5	
																								Cossura pygodactylata	4	
5, 220, Dabob Bay	18.6	2	0.1				98.9		45.4	**	45.3		15.2	++	26	16	0.9	10	12	5	1	7	1	Macoma carlottensis	4	no
																								Nephtys cornuta	3	
																								Pacifoculodes zernovi	3	
																								Mysidacea	2	
6, 221, Hood Canal (central)	36.4	3	0.2				100.0		106.6		9.9		12.4	++	100	23	0.9	10	64	8	0	24	4	Mediomastus sp	16	no
																								Axinopsida serricata	12	
																								Macoma carlottensis	12	
																								Heteromastus filobranchus	11	
6, 222, Hood Canal (central)	36.4	1	0.1				101.1		105.3		111.7		7.4		219	34	0.7	8	82	104	0	30	3	Eudorella pacifica	68	no
																								Pectinaria californiensis	35	
																								Euphilomedes producta	18	
																								Prionospio (Minuspio) lighti	13	
6, 223, Hood Canal (central)	36.4	3	0.1				101.1		105.7		11.7		8.2		69	29	0.9	14	45	6	6	5	7	Leitoscoloplos pugettensis	11	no
																								Chaetoderma sp	5	
																								Brisaster latifrons	5	
																								Lumbrineris limicola	4	
7, 224, Hood Canal (south)	11.0	4	0.1				95.6		105.7		5.8		8.0		139	29	0.7	7	124	2	7	4	2	Sigambra bassi	54	no
																								Spiophanes berkeleyorum	19	
																								Paraprionospio pinnata	10	
																								Heteromastus filobranchus	10	

Appendix J. Continued.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
7, 225, Hood Canal (south)	11.0	4	0.1				96.7		106.4		2.7		9.4		144	15	0.5	2	134	0	0	7	3	Sigambra bassi	87	no
																								Paraprionospio pinnata	25	
																								Axinopsida serricata	7	
																								Glycinde polygnatha	6	
7, 226, Hood Canal (south)	11.0	3	0.1				105.6		103.1		14.6		6.5		286	27	0.7	5	205	28	0	48	5	Spiophanes berkeleyorum	100	no
																								Heteromastus filobranchus	55	
																								Macoma carlottensis	28	
																								Eudorella pacifica	26	
8, 227, Port of Shelton	15.2	16	0.2				103.2		97.5		1.1		56.6	+++	299	33	0.7	8	225	21	5	48	0	Nephtys cornuta	83	yes
																								Oligochaeta	42	
																								Capitella capitata hyperspecies	33	
																								Prionospio (Minuspio) lighti	19	
8, 228, Port of Shelton	15.2	5	0.1				101.1		98.8		1.6		21.3	++	237	35	0.8	9	156	19	0	59	3	Nephtys cornuta	52	yes
																								Capitella capitata hyperspecies	31	
																								Oligochaeta	18	
																								Macoma nasuta	16	
8, 229, Port of Shelton	15.2	7	0.1				104.3		99.2		1.0		26.4	++	269	45	0.8	10	131	96	0	40	2	Balanus sp	71	yes
																								Armandia brevis	35	
																								Capitella capitata hyperspecies	18	
																								Oligochaeta	17	
9, 230, Oakland Bay	3.3	8	0.2				97.9		95.6		1.7		27.0	++	297	27	0.4	3	31	210	1	49	6	Cyclopoida	206	no
																								Cryptomya californica	14	
																								Macoma nasuta	12	
																								Nutricola lordi	12	

Appendix J. Continued.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
9, 231, Oakland Bay	3.3	3	0.1				101.1		101.8		1.1		27.7	++	89	23	0.8	9	29	11	0	40	9	Nutricola lordi	25	no
																								Terebellides californica	12	
																								Macoma nasuta	10	
																								Pinnotheridae	5	
9, 232, Oakland Bay	3.3	5	0.1				102.2		84.4	*	2.6		14.1	++	82	21	0.9	9	30	15	5	29	3	Macoma nasuta	12	no
																								Pinnixa occidentialis	11	
																								Prionospio (Minuspio) lighti	10	
																								Nutricola lordi	9	
10, 233, Totten Inlet	5.7	3	0.1				100.0		106.1		1.6		12.7	++	212	24	0.8	7	132	44	14	20	2	Paraprionospio pinnata	44	no
																								Terebellides californica	26	
																								Pinnixa occidentialis	26	
																								Pholoe sp N1	23	
10, 234, Totten Inlet	5.7	3	0.1				96.9		102.5		4.2		8.0		116	18	0.7	4	98	8	0	7	3	Nephtys cornuta	38	no
																								Spiophanes berkeleyorum	31	
																								Paraprionospio pinnata	12	
																								Terebellides californica	6	
10, 235, Totten Inlet	5.7	4	0.2	Metals: Mercury	Metals: Mercury	Metals: Mercury	100.0		70.2	**	3.8		8.3		259	38	0.8	12	121	39	48	32	19	Amphiodia (Amphispina) urtica/periercta	41	no
																								Pholoe sp N1	25	
																								Levinsenia gracilis	21	
																								Paraprionospio pinnata	21	
12, 236, Budd Inlet	5.5	3	0.1				96.9		92.6		2.0		18.5	++	273	23	0.4	2	230	10	1	29	3	Aphelochaeta sp N1	204	yes
																								Odostomia sp	18	
																								Paraprionospio pinnata	13	
																								Turbonilla sp	5	

Appendix J. Continued.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
12, 237, Budd Inlet	5.5	3	0.1		Other: Benzoic Acid, Benzyl Alcohol	Other: Benzoic Acid, Benzyl Alcohol	101.1		103.6		1.6		11.4	++	886	30	0.5	3	204	220	445	8	9	Amphiodia (Amphispina) urtica/periercta	439	no
																								Eudorella pacifica	174	
																								Pholoe sp N1	127	
																								Aphelochaeta sp N1	51	
11, 238, Eld Inlet	4.0	3	0.1				100.0		107.0		0.8		16.1	++	441	22	0.4	2	57	318	20	23	23	Eudorella pacifica	304	no
																								Paraprionospio pinnata	29	
																								Amphiodia (Amphispina) urtica/periercta	20	
																								Stylatula elongata	17	
11, 239, Eld Inlet	4.0	3	0.1				101.0		106.6		4.2		8.4		576	29	0.6	4	131	328	81	10	26	Eudorella pacifica	262	no
																								Pholoe sp N1	82	
																								Amphiodia (Amphispina) urtica/periercta	71	
																								Pinnotheridae	31	
11, 240, Eld Inlet	4.0	4	0.1				97.9		7.8	**	4.3		15.0	++	40	10	0.9	5	37	2	0	1	0	Paraprionospio pinnata	10	no
																								Nephtys cornuta	7	
																								Spiophanes berkeleyorum	6	
																								Aphelochaeta sp N1	6	
12, 241, Budd Inlet	5.5	3	0.1				102.1		105.9		1.3		25.6	++	836	39	0.6	4	263	207	302	24	40	Amphiodia (Amphispina) urtica/periercta	232	no
																								Eudorella pacifica	197	
																								Pholoe sp N1	173	
																								Amphiodia sp	55	
13, 242, Port of Olympia	0.3	13	0.2				96.8		0.4	**	1.0		45.7	+++					0	0	0	0	0			yes

Appendix J. Continued.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
13, 243, Port of Olympia	0.3	23	0.4		Other: Benzoic Acid, Bis(2-Ethylhexyl) Phthalate	Other: Benzoic Acid	101.1		0.0	**	0.3	^	122.7	+++					0	0	0	0	0			yes
13, 244, Port of Olympia	0.3	4	0.1		Other: Phenol	Other: Phenol	98.9		100.1		0.7		20.1	++	123	18	0.6	4	112	1	1	7	2	Nephtys cornuta	57	yes
																								Paraprionospio pinnata	17	
																								Sigambra bassi	16	
																								Aphelochaeta sp N1	10	
14, 245, Pickering Passage/ Squaxin Island	10.5	1	0.1		Other: Benzyl Alcohol		81.1	*	106.4		7.3		1.8		838	103	0.8	23	418	100	8	232	80	Edwardsia sipunculoides	52	no
																								Paleanotus bellis	51	
																								Caulleriella pacifica	49	
																								Astyris gausapata	48	
14, 246, Pickering Passage/ Squaxin Island	10.5	0	0.1				101.1		106.6		7.9		4.2		691	98	0.8	25	509	20	2	137	23	Parvilucina tenuisculpta	76	no
																								Levinsenia gracilis	48	
																								Mediomastus sp	42	
																								Trochochaeta multisetosa	39	
14, 247, Pickering Passage/ Squaxin Island	10.5	1	0.1		Other: Benzyl Alcohol	Other: Benzyl Alcohol	98.9		106.4		6.6		2.7		1073	93	0.7	17	522	52	15	130	354	Edwardsia sipunculoides	311	no
																								Micropodarke dubia	220	
																								Polycirrus californicus	45	
																								Rochefortia tumida	26	
15, 248, Henderson Inlet	1.6	3	0.1				93.8		103.8		3.6		9.1		391	27	0.7	6	82	185	72	37	15	Eudorella pacifica	130	no
																								Amphiodia (Amphispina) urtica/periercta	64	
																								Pholoe sp N1	44	
																								Nutricola lordi	30	

Appendix J. Continued.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
15, 249, Henderson Inlet	1.6	3	0.1				100.0		107.0		1.4		10.8		519	29	0.5	4	110	313	51	21	24	Eudorella pacifica	295	no
																								Amphiodia (Amphispina) urtica/periercta	51	
																								Paraprionospio pinnata	36	
																								Oligochaeta	29	
15, 250, Henderson Inlet	1.6	2	0.1		Other: Benzoic Acid, Phenol	Other: Benzoic Acid, Phenol	97.9		104.6		3.7		10.4		527	30	0.4	2	55	398	50	10	14	Eudorella pacifica	361	no
																								Amphiodia (Amphispina) urtica/periercta	42	
																								Sigambra bassi	19	
																								Heterophoxus affinis	19	
16, 251, Case Inlet	20.8	1	0.1				100.0		102.5		2.3		21.9	++	319	47	0.7	11	260	15	1	38	5	Levinsenia gracilis	84	no
																								Aricidea (Allia) ramosa	51	
																								Sigambra bassi	27	
																								Parvilucina tenuisculpta	22	
16, 252, Case Inlet	20.8	2	0.1				97.9		84.2	*	7.4		20.0	++	188	28	0.8	7	99	31	0	30	28	Aricidea (Allia) ramosa	39	no
																								Levinsenia gracilis	29	
																								Virgularia sp	26	
																								Parvilucina tenuisculpta	18	
16, 253, Case Inlet	20.8	2	0.1				97.9		101.4		4.9		9.0		209	45	0.8	14	153	9	1	31	15	Aricidea (Allia) ramosa	34	no
																								Levinsenia gracilis	29	
																								Parvilucina tenuisculpta	20	
																								Dipolydora caulleryi	15	

Appendix J. Continued.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
17, 254, Nisqually Reach	11.9	0	0.0				91.8	*	101.3		10.0		2.1		164	56	0.8	18	48	73	1	36	6	Euphilomedes carcharodonta	46	no
																								Astyris gausapata	21	
																								Westwoodilla caecula	6	
																								Calanoida	5	
17, 255, Nisqually Reach	11.9	0	0.1				96.9		101.1		5.3		7.4		220	51	0.8	13	176	4	3	27	10	Dipolydora cardalia	41	no
																								Levinsenia gracilis	37	
																								Parvilucina tenuisculpta	14	
																								Sigambra bassi	13	
17, 256, Nisqually Reach	11.9	0	0.1				95.9		100.1		8.1		5.5		468	69	0.8	15	290	34	98	30	16	Dipolydora cardalia	74	no
																								Amphiodia (Amphispina) urtica/periercta	68	
																								Levinsenia gracilis	46	
																								Prionospio steenstrupi	22	
18, 257, Drayton Passage	6.7	1	0.1				96.9		100.5		2.8		15.7	++	496	57	0.6	7	403	25	2	21	45	Levinsenia gracilis	209	no
																								Aricidea (Allia) ramosa	77	
																								Sigambra bassi	35	
																								Virgularia sp	25	
18, 258, Drayton Passage	6.7	0	0.1				97.9		100.1		7.4		2.0		297	81	0.8	24	93	86	27	86	5	Euphilomedes carcharodonta	44	no
																								Rochefortia tumida	24	
																								Rhepoxynius boreovariatus	14	
																								Astyris gausapata	13	
18, 259, Drayton Passage	6.7	0	0.1				102.1		100.9		5.6		2.3		687	79	0.6	8	241	23	380	24	19	Amphiodia (Amphispina) urtica/periercta	313	no
																								Scoletoma luti	60	
																								Amphiodia sp	59	
																								Dipolydora cardalia	30	

Appendix J. Continued.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
19, 260, East Anderson Island/No. Cormorant Passage	16.5	1	0.1		Other: Benzoic Acid	Other: Benzoic Acid	99.0		100.1		6.6		12.4	++	244	53	0.9	18	149	46	10	34	5	Levinsenia gracilis	21	no
																								Dipolydora socialis	19	
																								Sigambra bassi	18	
																								Parvilucina tenuisculpta	17	
19, 261, East Anderson Island/No. Cormorant Passage	16.5	1	0.1				99.0		99.9		5.1		9.0		316	63	0.8	20	213	19	25	42	17	Dipolydora socialis	35	no
																								Trochochaeta multisetosa	27	
																								Parvilucina tenuisculpta	26	
																								Levinsenia gracilis	21	
19, 262, East Anderson Island/No. Cormorant Passage	16.5	0	0.1				98.0		97.9		7.1		5.2		592	106	0.8	23	275	145	133	23	16	Amphiodia (Amphispina) urtica/periercta	131	no
																								Euphilomedes carcharodonta	44	
																								Rhepoxynius boreovariatus	28	
																								Ampelisca lobata	26	
20, 263, Carr Inlet	26.6	0	0.1				101.0		100.3		14.5		3.5		391	70	0.8	19	277	22	13	76	3	Praxillella sp	38	no
																								Levinsenia gracilis	32	
																								Trochochaeta multisetosa	32	
																								Axinopsida serricata	30	
20, 264, Carr Inlet	26.6	4	0.2				101.0		100.7		15.8		7.0		107	22	0.8	7	35	1	0	59	12	Axinopsida serricata	40	no
																								Sigambra bassi	9	
																								Parvilucina tenuisculpta	9	
																								Levinsenia gracilis	8	
20, 265, Carr Inlet	26.6	3	0.1				99.0		98.7		6.2		12.8	++	182	27	0.8	7	113	8	0	59	2	Parvilucina tenuisculpta	38	no
																								Prionospio (Minuspio) lighti	32	
																								Levinsenia gracilis	26	
																								Cossura pygodactylata	14	

Appendix J. Continued.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
21, 266, Hale Passage	3.6	0	0.0		Other: Benzoic Acid	Other: Benzoic Acid	101.0		100.5		6.6		2.0		274	66	0.9	22	150	18	0	96	10	Mediomastus californiensis	33	no
																								Parvilucina tenuisculpta	22	
																								Mediomastus sp	15	
																								Chaetozone sp N2	14	
21, 267, Hale Passage	3.6	0	0.1				100.0		100.1		6.8		4.1		266	73	0.8	20	146	84	3	27	6	Euphilomedes carcharodonta	60	no
																								Dipolydora socialis	27	
																								Prionospio steenstrupi	23	
																								Streblosoma sp	20	
21, 268, Hale Passage	3.6	0	0.1				99.0		99.9		6.4		1.6		222	57	0.8	17	147	30	3	33	9	Chaetozone sp N2	32	no
																								Mediomastus californiensis	23	
																								Odontosyllis phosphorea	13	
																								Diopatra ornata	13	
22, 269, Gig Harbor	0.2	0	0.1				104.5		100.9		2.8		33.3	++	1107	61	0.5	3	922	98	0	87	0	Aphelochaeta sp	407	yes
																								Aphelochaeta sp N1	229	
																								Rhynchospio glutaea	195	
																								Odostomia sp	41	
22, 270, Gig Harbor	0.2	1	0.1				97.7		100.5		1.0		31.3	++	1287	78	0.5	3	1178	60	0	38	11	Aphelochaeta sp	559	yes
																								Aphelochaeta sp N1	380	
																								Lumbrineris californiensis	32	
																								Phyllochaetopterus prolifica	30	
22, 271, Gig Harbor	0.2	19	0.3				100.0		100.7		2.0		87.0	+++	374	63	0.7	11	98	142	23	108	3	Eudorella pacifica	56	no
																								Euphilomedes carcharodonta	53	
																								Axinopsida serricata	47	
																								Mediomastus sp	37	

Appendix J. Continued.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
23, 272, Colvos Passage	13.9	0	0.1				97.0		100.5		29.8		3.9		367	96	0.9	31	205	102	2	48	10	Mediomastus sp	31	no
																								Mediomastus californiensis	20	
																								Dipolydora socialis	17	
																								Caprella sp	16	
23, 273, Colvos Passage	13.9	1	0.1				91.0		100.3		31.5		2.3		265	75	0.8	25	133	86	5	31	10	Mediomastus sp	34	no
																								Tritella pilimana	31	
																								Sabellidae	20	
																								Pinnotheridae	13	
23, 274, Colvos Passage	13.9	0	0.1				91.1		100.5		28.4		3.7		633	54	0.5	4	537	57	0	35	4	Aphelochaeta sp	256	no
																								Aphelochaeta sp N1	177	
																								Pinnotheridae	34	
																								Olivella baetica	24	
24, 275, Quarter-master Harbor	3.4	0	0.1				98.9		99.7		51.1		5.2		510	90	0.8	20	275	120	2	109	4	Parvilucina tenuisculpta	67	no
																								Euphilomedes carcharodonta	53	
																								Euphilomedes producta	39	
																								Polycirrus sp	37	
24, 276, Quarter-master Harbor	3.4	5	0.2				105.7		99.5		0.7		29.2	++	286	41	0.7	7	177	3	0	101	5	Nutricola lordi	83	no
																								Terebellides californica	66	
																								Scalibregma inflatum	29	
																								Heteromastus filobranchus	17	
24, 277, Quarter-master Harbor	3.4	4	0.1				94.3		100.5		1.3		16.4	++	265	49	0.8	15	151	62	28	13	11	Eudorella pacifica	34	no
																								Terebellides californica	29	
																								Amphiodia (Amphispina) urtica/periercta	28	
																								Polycirrus californicus	22	

Appendix J. Continued.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
25, 278, East Passage	22.6	10	0.2				103.4		100.9		18.1		78.9	+++	1450	90	0.6	10	252	644	11	534	9	Axinopsida serricata	372	no
																								Eudorellopsis integra	308	
																								Euphilomedes producta	165	
																								Macoma carlottensis	77	
25, 279, East Passage	22.6	5	0.1				100.0		100.1		3.6		24.5	++	454	39	0.5	4	62	55	3	319	15	Axinopsida serricata	292	no
																								Eudorellopsis integra	26	
																								Eudorella pacifica	16	
																								Levinsenia gracilis	13	
25, 280, East Passage	22.6	1	0.1				97.7		98.7		175.3		1.5		193	66	0.9	26	124	29	1	34	5	Chaetozone sp N2	38	no
																								Astyris gausapata	15	
																								Diopatra ornata	9	
																								Spiophanes bombyx	9	
26, 281, Outer Commencement Bay	3.2	5	0.1				98.9		100.1		3.8		11.8	++	344	56	0.7	13	144	33	3	158	6	Axinopsida serricata	104	no
																								Levinsenia gracilis	36	
																								Macoma carlottensis	30	
																								Prionospio (Minuspio) lighti	21	
26, 282, Outer Commencement Bay	3.2	7	0.2				100.0		98.9		4.3		27.8	++	533	66	0.6	10	269	55	3	192	14	Axinopsida serricata	169	no
																								Levinsenia gracilis	132	
																								Cossura pygodactylata	27	
																								Mediomastus sp	14	
26, 283, Outer Commencement Bay	3.2	4	0.1				94.6		100.5		11.6		18.8	++	723	61	0.6	6	178	133	2	382	28	Axinopsida serricata	337	no
																								Eudorellopsis integra	94	
																								Levinsenia gracilis	43	
																								Macoma carlottensis	29	
26, 284, Outer Commencement Bay	3.2		0.2				101.1		100.5		6.5		7.0		609	89	0.7	19	217	126	2	257	7	Axinopsida serricata	163	no
																								Euphilomedes producta	73	
																								Macoma carlottensis	50	
																								Levinsenia gracilis	19	

Appendix J. Continued.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
27, 285, S. E. Commencement Bay (shoreline)	0.8	3	0.1				101.1		100.7		9.1		19.8	++	635	98	0.8	24	264	207	16	144	4	Euphilomedes carcharodonta	124	no
																								Parvilucina tenuisculpta	39	
																								Pinnotheridae	36	
																								Chaetozone nr setosa	31	
27, 286, S. E. Commencement Bay (shoreline)	0.8	8	0.1				102.2		100.7		5.8		26.4	++	758	70	0.6	9	182	102	1	468	5	Axinopsida serricata	316	no
																								Macoma carlottensis	83	
																								Euphilomedes producta	52	
																								Astyris gausapata	36	
27, 287, S. E. Commencement Bay (shoreline)	0.8	20	0.5	LPAHs: Phenanthrene, Total LPAH			95.7		100.1		4.7		121.7	+++	1879	101	0.6	9	325	621	31	898	4	Axinopsida serricata	495	no
																								Euphilomedes carcharodonta	317	
																								Euphilomedes producta	193	
																								Macoma sp	172	
28, 288, S. E. Commencement Bay	1.1	7	0.2				101.1		100.9		9.2		12.8	++	1480	65	0.5	6	1332	67	0	72	9	Cossura pygodactylata	862	no
																								Trochochaeta multisetosa	106	
																								Levinsenia gracilis	45	
																								Ampharete cf crassiseta	40	
28, 289, S. E. Commencement Bay	1.1	8	0.1				104.3		101.3		11.0		18.2	++	986	71	0.7	10	767	44	0	169	6	Ampharete cf crassiseta	137	no
																								Cossura pygodactylata	114	
																								Axinopsida serricata	104	
																								Trochochaeta multisetosa	100	

Appendix J. Continued.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
28, 290, S. E. Commencement Bay	1.1	8	0.1				100.0		100.9		7.9		18.8	++	2291	72	0.5	5	2124	52	0	109	6	Cossura pygodactylata	1248	no
																								Ampharete cf crassiseta	193	
																								Ampharetidae	135	
																								Trochochaeta multisetosa	90	
29, 291, N.E. Commencement Bay	1.1	6	0.1				96.7		100.5		5.5		22.0	++	622	53	0.6	5	215	22	5	378	2	Axinopsida serricata	315	no
																								Ampharete finmarchica	57	
																								Levinsenia gracilis	52	
																								Macoma carlottensis	31	
29, 292, N.E. Commencement Bay	1.1	6	0.1				95.5		99.5		4.0		28.4	++	974	86	0.7	13	533	48	22	357	14	Axinopsida serricata	281	no
																								Levinsenia gracilis	192	
																								Cossura pygodactylata	41	
																								Euchone incolor	32	
29, 293, N.E. Commencement Bay	1.1	15	0.2				92.2		99.3		0.4	^	109.0	+++	2235	86	0.5	4	1792	47	10	363	23	Aphelochaeta sp	1262	yes
																								Alvania compacta	220	
																								Aphelochaeta sp N1	153	
																								Aphelochaeta monilaris	70	

Appendix J. Continued.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
30, 294, Thea Foss Waterway	0.1	27	4.3	Metals: Lead; **LPAHs:** 2-Methylnaphthalene, Acenaphthene, Acenaphthylene, Anthracene, Fluorene, Phenanthrene, Total LPAHs; **HPAHs:** Benzo(a)anthracene, Benzo(a)pyrene, Chrysene, Dibenzo(a,h) anthracene, Fluoranthene, Naphthalene, Pyrene, Total HPAHs, Total PAHs; **Other:** Total PCBs	Metals: Mercury; **LPAHs:** Acenaphthene, Fluorene, Phenanthrene; **HPAHs:** Benzo(g,h,i)perylene, Fluoranthene, Indeno(1,2,3-c,d)pyrene; **Other:** Dibenzofuran, 2,4-Dimethylphenol, Bis(2Ethylhexyl) Phthalate, Total Aroclors	Metals: Mercury; **Other:** 2,4-Dimethylphenol	90.2	*	28.8	**	0.3	^	1994.9	+++	304	43	0.8	10	103	36	0	164	1	Alvania compacta Lacuna vincta Capitella capitata hyperspecies Armandia brevis	69 31 31 23	yes
30, 295, Thea Foss Waterway	0.1	21	0.5	LPAHs: Total LPAHs	Other: Butylbenzylphthalate		101.1		100.5		1.4		529.1	+++	2924	53	0.4	3	2259	96	41	521	7	Aphelochaeta sp Axinopsida serricata Aphelochaeta sp N1 Pinnotheridae	1708 360 260 88	yes
30, 296, Thea Foss Waterway	0.1	21	0.5	LPAHs: Total LPAHs; **HPAHs**: Pyrene	HPAHs: Benzo(g,h,i)perylene, Indeno(1,2,3-c,d)pyrene		95.7		100.7		1.1		355.7	+++	1633	79	0.6	8	1070	91	38	427	7	Aphelochaeta sp N1 Axinopsida serricata Rochefortia tumida Cossura pygodactylata	612 237 94 73	yes
31, 297, Middle Waterway	0.0	19	0.4				100.0		99.1		3.0		44.2	+++	1847	117	0.6	12	1283	77	56	422	9	Aphelochaeta sp N1 Axinopsida serricata Parvilucina tenuisculpta Alvania compacta	777 179 82 51	yes

Appendix J. Continued.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
31, 298, Middle Waterway	0.0	18	0.3				94.6		101.0		0.9		73.3	+++	888	86	0.7	12	641	94	11	141	1	Aphelochaeta sp N1	232	no
																								Armandia brevis	92	
																								Lumbrineris californiensis	49	
																								Prionospio steenstrupi	48	
31, 299, Middle Waterway	0.0	22	1.1	Metals: Copper, Mercury; **LPAHs:** Acenaphthene, Anthracene, Fluorene, Phenanthrene, Total LPAHs; **HPAHs:** Benzo(a)anthracene, Benzo(a)pyrene, Dibenzo(a,h) anthracene, Pyrene, Total HPAHs	Metals: Arsenic, Cooper, Mercury; **LPAHs:** Acenaphthene, Fluorene, Phenanthrene, Total LPAHs; **HPAHs:** Benzo(a) anthracene, Benzo(a) pyrene, Benzo(g,h,i)perylene, Chrysene, Dibenzo(a,h) anthracene, Fluoranthene, Indeno(1,2,3-c,d)pyrene, Total HPAHs; **Other:** Dibenzofuran	Metals: Cooper, Mercury; **LPAHs:** Ace-naphthene; HPAHs: Dibenzo(a,h) anthracene	93.5		100.3		2.0		119.7	+++	1296	81	0.5	8	1179	38	5	64	10	Aphelochaeta sp N1	706	yes
																								Lumbrineris californiensis	65	
																								Prionospio steenstrupi	52	
																								Notomastus tenuis	50	
32, 300, Blair Waterway	0.4	4	0.1				101.1		100.9		3.3		36.7	++	889	50	0.6	5	507	6	0	375	1	Axinopsida serricata	353	yes
																								Aphelochaeta sp N1	152	
																								Aphelochaeta monilaris	74	
																								Scoletoma luti	48	
32, 301, Blair Waterway	0.4	3	0.1				93.3		100.1		2.6		33.3	++	1010	50	0.5	3	726	6	0	278	0	Aphelochaeta sp N1	410	yes
																								Axinopsida serricata	257	
																								Chaetozone nr setosa	92	
																								Scoletoma luti	34	

Appendix J. Concluded.

Stratum, Sample, Location	sampled-wtd area (km2)	Number of ERLs exceeded	Mean ERM Quotient	Compounds exceeding ERMs	Compounds exceeding SQSs	Compounds exceeding CSLs	Amphipod Survival as % of Control	Significance	Mean Urchin Fertilization in 100% pore water as % of Control	Significance	Microtox EC50 (mg/ml)	Significance	Cytochrome P-450 RGS as ugB[a]P/g	Significance	Total Abundance	Species Richness	Evenness	Species Dominance Index	Annelid Abundance	Arthropod Abundance	Echinoderm Abundance	Mollusca Abundance	Misc. Abundance	Dominant Species	Count	Infaunal Hit
32, 302, Blair Waterway	0.4	2	0.2				94.4		100.7		4.3		19.9	++	1145	61	0.6	5	672	28	4	440	1	Axinopsida serricata	377	yes
																								Aphelochaeta sp N1	252	
																								Aphelochaeta monilaris	142	
																								Scoletoma luti	57	
33, 303, Hylebos Waterway	0.2	24	2.1	Other: Total PCBs	Other: Hexachlorobenzene, Total Aroclors		101.1		98.3		0.9		176.2	+++	777	55	0.5	5	572	22	0	177	6	Aphelochaeta sp N1	383	yes
																								Axinopsida serricata	90	
																								Aphelochaeta monilaris	63	
																								Scoletoma luti	40	
33, 304, Hylebos Waterway	0.2	12	0.6		Other: Hexachlorobenzene, Phenol, Total Aroclors		101.1		99.7		1.2		104.8	+++	535	56	0.6	6	469	12	0	51	3	Aphelochaeta sp N1	258	yes
																								Euchone incolor	41	
																								Prionospio steenstrupi	31	
																								Scoletoma luti	29	
33, 305, Hylebos Waterway	0.2	19	1.1		Other: Hexachlorobenzene		86.0		100.7		0.8		73.3	+++	922	47	0.4	2	836	25	2	57	2	Aphelochaeta sp N1	632	yes
																								Aphelochaeta monilaris	67	
																								Scoletoma luti	57	
																								Axinopsida serricata	28	

Amphipod: *p<0.05, avg. survival >80% of CLIS control; ** p<0.05 and avg. survival <80% of control - one-way, unpaired t-test

^ = mean EC50 <0.51 mg/ml determined as the 80% lower prediction limit (LPL) with the lowest (i.e., most toxic) samples removed, but >0.06 mg/ml determined as the 90% lower prediction limit (LPL) earlier in this report.

Urchin fertilization: *p<0.05, **p<0.01 and <80% of controls. Dunnett's T-test

Cytochrome RGS as ugB[a]P/g: ++value 11.1 benzo[a]pyrene equivalents (ug/g sediment) determined as the 80% upper prediction limit (UPL); +++ = value >37.1 benzo[a]pyrene equivalents (ug/g sediment) determined as the 90% upper prediction limit (UPL)